APPENDIX E

TECHNICAL MEMORANDUM:
Electrical Energy Grid Life-Cycle Inventories for the CDP

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TECHNICAL MEMORANDUM: Electrical Energy Grid Life-Cycle Inventories for the CDP

1. INTRODUCTION

1.1 Background

The U.S. Environmental Protection Agency's (EPA) Design for the Environment (DfE) Program Computer Display Project (CDP) is conducting a combined Cleaner Technologies Substitutes Assessment (CTSA) and life-cycle assessment (LCA) to evaluate the relative environmental impacts, cost, and performance of cathode ray tube (CRT) and active matrix liquid crystal display (AMLCD) desktop computer monitors. Initially the project is conducting an LCA to determine the relative potential environmental impacts of the monitors, including impacts from materials extraction, materials processing, manufacturing (monitor and components), use, and end-of-life disposition. Transportation information is also included within and between each stage.

LCA has four major components:

1. goal definition and scoping,
2. life-cycle inventory (LCI),
3. life-cycle impact assessment (LCIA), and
4. improvement assessment.

The LCI is a collection of inputs (materials, energy, and other resources) and outputs (products, wastes and emissions) for processes throughout the product's life cycle. The LCIA characterizes the potential relative impacts of these inputs and outputs per functional unit, where the functional unit is defined in this project as one monitor over its lifetime. Improvement assessment is the component where those who are in the position to make changes in either the design or manufacture of the product review the results and decide on ways to implement environmental improvements.

The focus of this technical memorandum (TM) is on the LCI component of the LCA. Established LCI methodology accounts for electricity requirements throughout the life cycle of a product system. Wherever electricity is used in a process in the product system, the LCI typically includes the inputs and outputs from the generation of that electricity. This TM presents the input and output inventory data that are used to calculate the impacts from electricity generation for the CDP. The inventory data were developed by the University of Tennessee Center for Clean Products and Clean Technologies (CCPCT) from existing data for the various fuels (e.g., coal, petroleum) used by electric utilities around the United States. Two inventories illustrate the amount of materials consumed (inputs) and pollutants released (outputs) to generate one kilowatthour (kWh) of electricity, based on the average U.S. and the average Japanese electrical grids. The data are presented in units of grams of material input or emission output per kWh (g/kWh) in almost all cases, excluding radioactive emissions which are presented in Becquerels per kWh [Bq/kWh, where a Becquerel is the Système Internationale (SI) unit for radioactivity]. All of the inputs and outputs in the electric grid inventories have been multiplied by the electricity consumption rate for each process in the product system where electricity is used. These input and output data are not used with LCI data collected from secondary sources that already include inputs and outputs from electricity generation. The two electric grid inventory data sets presented in this TM are for the average U.S. electrical grid and the average Japanese electric grid.

1.2 Boundaries of the Analysis

In addition to the geographic boundary (i.e., U.S. and Japanese data only), the boundaries of the data presented in this TM are defined by the generation categories included in the analysis (e.g., coal, nuclear) and the life-cycle stages evaluated for the various generation categories (e.g., extraction, generation). A U.S. electric grid inventory was developed first and the Japanese grid inventory is simply a modification of the U.S. inventory, which applies the average Japanese electric grid to the input and output data found for the United States. This will not account for any effects of different control technologies used in Japan compared to the United States. The majority of this TM focuses on collecting U.S. data, and mentions when the Japanese grid is applied.

Table 1 presents the electricity generation categories, associated fuels types, percent breakdown for U.S. electricity generation in 1997 and whether or not that category is included in this inventory. (While 1998 is the target year for the overall CDP, this TM was targeted for 1997 as almost no data could be obtained that was relative to 1998.) Coal is the dominant generation category and fuel type in the U.S., accounting for over 55 percent of 1997 electricity production. Non-renewable fuels (coal, gas, petroleum, and uranium) plus water (for hydroelectric plants) together provide greater than 99 percent of U.S. electricity. Table 1 also lists the average Japanese breakdown of fuels.

Table 1. Fuel Types Used to Generate Electricity in U.S. and Japan in 1997

Generation Category	Fuel	U.S. Generation % Breakdown	Japanese % Breakdown	Included in Electric Grid Analysis?
Coal	Coal	57.23%	18%	Yes
Gas	Gas	9.07%	20%	Yes
Petroleum	Petroleum	2.53%	21%	Yes
Nuclear	Uranium	20.14%	31%	Yes
Hydro	Water	10.79%	9%	No
Renewables	Wind, biomass, heat from sun, heat from earth	0.24%	1%	No
Total		100%	100%	

Sources: EIA 1999a, EIA 1997.

Individual input and output inventories were developed for each of the generation categories listed in Table 1, except hydro and renewables. Hydroelectric facilities, which constitute nearly 11% of the U.S. electric grid, were excluded due to the scarcity of data on hydroelectric inputs and outputs. Known impacts of hydroelectric facilities primarily relate to reservoir formation, which includes habitat destruction and its concurrent effects on biodiversity, and the generation of the greenhouse gases methane and carbon dioxide from the flooding of wetlands during and after reservoir formation. Habitat destruction is not included as an impact category *per se* within the CDP LCIA methodology (see Chapter 3 of main report), but global warming is included. Furthermore, EPA has concluded there is currently no adequate basis for estimating the emissions and sinks from the flooding of wetlands (EPA 1998a).

Renewables were excluded because they accounted for only a small fraction (0.24%) of total U.S. electricity production in 1997. In addition, little or no data exist on material inputs and pollutant outputs for renewable electricity generation processes.

The following life-cycle stages are associated with electricity generation:

- Extraction of ores and fluids from the earth and any necessary transportation to the initial processing point (Materials Extraction);
- Initial and secondary processing of those ores/fluids into usable fuels, and the associated transportation between processing points and to the generating stations (Materials Processing);
- Combustion or use of the fuel and the onsite control of pollutants, and transmission and distribution of the generated electricity to the points of use (Manufacturing);

NOTE: This description excludes the process flows of renewable energy sources.

Little or no data were available for the extraction and initial and secondary processing of ores and fluids into fuels, except for some data for coal extraction and processing. Therefore, most of the electrical grid input and output data presented in this TM only include the manufacturing life-cycle stage (generation and transmission and distribution of electricity) as shown in Table 2.

Table 2. Fuel Life-Cycle Substages Captured in Electric Grid LCI Data

Life-Cycle Substages	Coal	Gas	Petroleum	Uranium
Extraction	P	N	N	N
Transport to Initial Processing	N	N	N	N
Initial Processing	P	N	N	N
Transport to secondary processing	NA	NA	NA	N
Secondary processing	NA	NA	NA	N
Transport to generating stations	N	N	N	N
Electricity generation	I	I	I	I
Transmission and Distribution	I	I	I	I

I = Included in inventory; P = Partially included in inventory; N = Not included in inventory; NA = Not applicable.

It should also be noted that this electric grid inventory relates only to *utility*-based generation. Electric power generation in the Unites States can be broken down into two main categories: utility and nonutility. In simplified terms, most electricity generating entities that are not classified as utilities fall in the nonutility category, and include many cogeneration facilities and small and independent power producers. About 65% of nonutility production is attributed to the manufacturing sector (EIA 1998a), and nonutility production as a whole constitutes just over 10% of the total power produced by the electric power industry. The inputs and outputs of nonutility electricity production are excluded here due to a lack of detailed data on the associated emissions and wastes.

1.3 Organization of the TM

The remainder of this document provides supporting information on the development of the electric grid data. It is organized into six sections: results summary, methodology, fuel-specific results, data sources and quality, limitations and conclusions. Supporting tables are presented as necessary in the Appendices.

2. RESULTS SUMMARY

Table 3a presents the primary and ancillary materials consumed and products and environmental burdens produced during the generation of 1 kilowatthour (kWh) in the United States, based on the national 1997 generation percent breakdown (see Table 1). Similarly, Table 3b presents the inventory for the Japanese grid. All inputs and outputs listed in Tables 3a and b are presented on a per kWh basis.

Section 3 of this TM discusses the methods used to calculate the nationwide U.S. electric grid inventory data. Spreadsheets were used to organize and manipulate all of the inventory data, and those spreadsheets are shown in Attachments A through E and contain supporting data source, assumptions, and limitations information.

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
PRIMARY INPUTS					
Coal, avg. (in ground)	2.83E+02	G	Input	Primary material	
Natural gas	2.20E+01	G	Input	Primary material	
Petroleum (in ground)	5.99E+00	G	Input	Primary material	
Uranium, yellowcake	7.64E-03	G	Input	Primary material	
ANCILLARY INPUTS					
Lime	1.67E+00	G	Input	Ancillary material	
Limestone	3.79E+00	G	Input	Ancillary material	
Water	1.79E+03	G	Input	Water	
PRODUCT					
Electricity	1.00E+00	KWH	Output	Energy	
AIR EMISSIONS					
1,1,1-Trichloroethane	3.02E-06	G	Output	Airborne	air
1,2-Dichloroethane	5.65E-06	G	Output	Airborne	air
2,3,7,8-TCDD	2.02E-12	G	Output	Airborne	air
2,3,7,8-TCDF	7.20E-12	G	Output	Airborne	air
2,4-Dinitrotoluene	3.96E-08	G	Output	Airborne	air
2-Chloroacetophenone	9.89E-07	G	Output	Airborne	air
2-Methylnaphthalene	4.20E-09	G	Output	Airborne	air
5-Methyl chrysene	3.11E-09	G	Output	Airborne	air
Acenaphthene	8.94E-08	G	Output	Airborne	air
Acenaphthylene	3.55E-08	G	Output	Airborne	air
Acetaldehyde	8.05E-05	G	Output	Airborne	air
Acetophenone	2.12E-06	G	Output	Airborne	air
Acrolein	4.10E-05	G	Output	Airborne	air
Anthracene	3.07E-08	G	Output	Airborne	air
Antimony	6.87E-06	G	Output	Airborne	air
Arsenic	5.91E-05	G	Output	Airborne	air
Barium	3.24E-06	G	Output	Airborne	air
Benzene	1.84E-04	G	Output	Airborne	air
Benzo[a]anthracene	1.46E-08	G	Output	Airborne	air
Benzo[a]pyrene	5.37E-09	G	Output	Airborne	air
Benzo[b,j,k]fluoranthene	1.68E-08	G	Output	Airborne	air
Benzo[g,h,i]perylene	5.68E-09	G	Output	Airborne	air
Benzyl chloride	9.89E-05	G	Output	Airborne	air
Beryllium	3.01E-06	G	Output	Airborne	air
Biphenyl	2.40E-07	G	Output	Airborne	air
Bromoform	5.51E-06	G	Output	Airborne	air
Bromomethane	2.26E-05	G	Output	Airborne	air
Cadmium	7.59E-06	G	Output	Airborne	air

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Carbon dioxide	7.00E+02	G	Output	Airborne	air
Carbon disulfide	1.84E-05	G	Output	Airborne	air
Carbon monoxide	1.27E-01	G	Output	Airborne	air
Chloride ions	2.86E-04	G	Output	Airborne	air
Chlorobenzene	3.11E-06	G	Output	Airborne	air
Chloroform	8.33E-06	G	Output	Airborne	air
Chromium (III)	3.83E-05	G	Output	Airborne	air
Chromium (VI)	1.14E-05	G	Output	Airborne	air
Chrysene	1.61E-08	G	Output	Airborne	air
Cobalt	1.91E-05	G	Output	Airborne	air
Copper	1.57E-06	G	Output	Airborne	air
Cumene	7.49E-07	G	Output	Airborne	air
Cyanide (-1)	3.53E-04	G	Output	Airborne	air
Di(2-ethylhexyl)phthalate	1.03E-05	G	Output	Airborne	air
Dibenzo[a,h]anthracene	1.38E-09	G	Output	Airborne	air
Dichloromethane	4.10E-05	G	Output	Airborne	air
Dimethyl sulfate	6.78E-06	G	Output	Airborne	air
Dioxins, remaining unspeciated	9.21E-11	G	Output	Airborne	air
Ethyl Chloride	5.93E-06	G	Output	Airborne	air
Ethylbenzene	1.33E-05	G	Output	Airborne	air
Ethylene dibromide	1.70E-07	G	Output	Airborne	air
Fluoranthene	1.06E-07	G	Output	Airborne	air
Fluorene	1.32E-07	G	Output	Airborne	air
Fluoride	3.08E-05	G	Output	Airborne	air
Formaldehyde	1.33E-04	G	Output	Airborne	air
Furans, remaining unspeciated	1.47E-10	G	Output	Airborne	air
Hexane	9.46E-06	G	Output	Airborne	air
Hydrochloric acid	1.70E-01	G	Output	Airborne	air
Hydrofluoric acid	2.12E-02	G	Output	Airborne	air
Indeno(1,2,3-cd)pyrene	1.04E-08	G	Output	Airborne	air
Isophorone	8.19E-05	G	Output	Airborne	air
Lead	2.01E-05	G	Output	Airborne	air
Magnesium	1.55E-03	G	Output	Airborne	air
Manganese	7.18E-05	G	Output	Airborne	air
Mercury	1.18E-05	G	Output	Airborne	air
Methane	1.02E+00	G	Output	Airborne	air
Methyl chloride	7.49E-05	G	Output	Airborne	air
Methyl ethyl ketone	5.51E-05	G	Output	Airborne	air
Methyl hydrazine	2.40E-05	G	Output	Airborne	air
Methyl methacrylate	2.83E-06	G	Output	Airborne	air

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Methyl tert-butyl ether	4.94E-06	G	Output	Airborne	air
Molybdenum	9.20E-07	G	Output	Airborne	air
Naphthalene	2.88E-06	G	Output	Airborne	air
Nickel	1.08E-04	G	Output	Airborne	air
Nitrogen oxides	1.85E+00	G	Output	Airborne	air
Nitrous oxide	5.35E-03	G	Output	Airborne	air
o-xylene	8.99E-08	G	Output	Airborne	air
PM-10	9.10E-02	G	Output	Airborne	air
Phenanthrene	3.95E-07	G	Output	Airborne	air
Phenol	2.26E-06	G	Output	Airborne	air
Phosphorus (yellow or white)	7.80E-06	G	Output	Airborne	air
Propionaldehyde	5.37E-05	G	Output	Airborne	air
Pyrene	5.25E-08	G	Output	Airborne	air
Selenium	1.84E-04	G	Output	Airborne	air
Styrene	3.53E-06	G	Output	Airborne	air
Sulfur dioxide	3.93E+00	G	Output	Airborne	air
TOCs, remaining unspeciated	9.07E-03	G	Output	Airborne	air
Tetrachloroethylene	6.07E-06	G	Output	Airborne	air
Toluene	4.00E-05	G	Output	Airborne	air
Vanadium	2.77E-05	G	Output	Airborne	air
Vinyl acetate	1.07E-06	G	Output	Airborne	air
Xylene (mixed isomers)	5.23E-06	G	Output	Airborne	air
Zinc (elemental)	2.40E-05	G	Output	Airborne	air
WATER RELEASES					
Sulfate ion (-4)	1.08E-01	G	Output	Waterborne	surface water
Suspended solids	2.80E-03	G	Output	Waterborne	surface water

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
WASTE					
Coal waste	8.01E+01	G	Output	Solid waste	landfill
Dust/sludge	3.10E+01	G	Output	Solid waste	landfill
Fly/bottom ash	2.00E+01	G	Output	Solid waste	landfill
Low-level radioactive waste	2.77E-03	G	Output	Radioactive waste	landfill
Uranium, depleted	8.30E-04	G	Output	Radioactive waste	landfill
RADIOACTIVE AIR EMISSIONS					
Argon-41 (isotope)	2.51E+01	Bq	Output	Radioactivity	air
Bromine-89 (isotope)	2.91E-06	Bq	Output	Radioactivity	air
Bromine-90 (isotope)	1.18E-06	Bq	Output	Radioactivity	air
Cesium-134 (isotope)	7.99E-05	Bq	Output	Radioactivity	air
Cesium-137 (isotope)	6.02E-04	Bq	Output	Radioactivity	air
Chromium-51 (isotope)	1.58E-03	Bq	Output	Radioactivity	air
Cobalt-57 (isotope)	4.24E-06	Bq	Output	Radioactivity	air
Cobalt-58 (isotope)	5.41E+00	Bq	Output	Radioactivity	air
Cobalt-60 (isotope)	4.07E-04	Bq	Output	Radioactivity	air
Iodine-131 (isotope)	1.90E-03	Bq	Output	Radioactivity	air
Iodine-132 (isotope)	3.86E-04	Bq	Output	Radioactivity	air
Iodine-133 (isotope)	1.76E+00	Bq	Output	Radioactivity	air
Iodine-134 (isotope)	2.00E-03	Bq	Output	Radioactivity	air
Iodine-135 (isotope)	1.01E-04	Bq	Output	Radioactivity	air
Krypton-85 (isotope)	4.17E+01	Bq	Output	Radioactivity	air
Krypton-85M (isotope)	2.02E+00	Bq	Output	Radioactivity	air
Krypton-87 (isotope)	7.52E-01	Bq	Output	Radioactivity	air
Krypton-88 (isotope)	3.53E+00	Bq	Output	Radioactivity	air
Manganese-54 (isotope)	2.24E-05	Bq	Output	Radioactivity	air
Niobium-95 (isotope)	8.89E-07	Bq	Output	Radioactivity	air
Rubidium-88 (isotope)	8.26E-03	Bq	Output	Radioactivity	air
Silver-110M (isotope)	2.65E-08	Bq	Output	Radioactivity	air
Technetium-99M (isotope)	1.19E-07	Bq	Output	Radioactivity	air
Tritium-3 (isotope)	5.90E+01	Bq	Output	Radioactivity	air
Xenon-131M (isotope)	3.40E+00	Bq	Output	Radioactivity	air
Xenon-133 (isotope)	4.91E+02	Bq	Output	Radioactivity	air
Xenon-133M (isotope)	3.26E+01	Bq	Output	Radioactivity	air
Xenon-135 (isotope)	1.85E+01	Bq	Output	Radioactivity	air
Xenon-135M (isotope)	3.54E-01	Bq	Output	Radioactivity	air
Xenon-138 (isotope)	1.17E+00	Bq	Output	Radioactivity	air

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Zirconium-95 (isotope)	2.30E-06	Bq	Output	Radioactivity	air
RADIOACTIVE WATER RELEASES					
Antimony-124 (isotope)	1.24E-02	Bq	Output	Radioactivity	surface water
Antimony-125 (isotope)	4.95E-02	Bq	Output	Radioactivity	surface water
Barium-140 (isotope)	9.21E-04	Bq	Output	Radioactivity	surface water
Cesium-134 (isotope)	3.32E-02	Bq	Output	Radioactivity	surface water
Cesium-136 (isotope)	3.84E-14	Bq	Output	Radioactivity	surface water
Cesium-137 (isotope)	4.99E-02	Bq	Output	Radioactivity	surface water
Chromium-51 (isotope)	5.98E-02	Bq	Output	Radioactivity	surface water
Cobalt-57 (isotope)	1.45E-03	Bq	Output	Radioactivity	surface water
Cobalt-58 (isotope)	5.90E-01	Bq	Output	Radioactivity	surface water
Cobalt-80 (isotope)	1.55E-01	Bq	Output	Radioactivity	surface water
Iodine-131 (isotope)	2.76E-02	Bq	Output	Radioactivity	surface water
Iodine-132 (isotope)	1.05E-02	Bq	Output	Radioactivity	surface water
Iodine-133 (isotope)	1.18E-02	Bq	Output	Radioactivity	surface water
Iodine-135 (isotope)	8.49E-03	Bq	Output	Radioactivity	surface water
Iron-55 (isotope)	1.41E-01	Bq	Output	Radioactivity	surface water
Iron-59 (isotope)	7.24E-03	Bq	Output	Radioactivity	surface water
Krypton-85M (isotope)	3.73E-02	Bq	Output	Radioactivity	surface water
Lanthanum-140 (isotope)	9.86E-04	Bq	Output	Radioactivity	surface water
Manganese-54 (isotope)	3.94E-02	Bq	Output	Radioactivity	surface water
Molybdenum-99 (isotope)	7.44E+04	Bq	Output	Radioactivity	surface water
Niobium-95 (isotope)	1.02E-02	Bq	Output	Radioactivity	surface water
Ruthenium-103 (isotope)	1.24E-03	Bq	Output	Radioactivity	surface water
Silver-110M (isotope)	1.45E-02	Bq	Output	Radioactivity	surface water
Sodium-24 (isotope)	2.21E-03	Bq	Output	Radioactivity	surface water
Strontium-89 (isotope)	2.39E-03	Bq	Output	Radioactivity	surface water
Strontium-90 (isotope)	5.61E-04	Bq	Output	Radioactivity	surface water
Strontium-95 (isotope)	6.18E-03	Bq	Output	Radioactivity	surface water
Sulfur-136 (isotope)	1.33E-03	Bq	Output	Radioactivity	surface water
Technetium-99M (isotope)	8.66E-04	Bq	Output	Radioactivity	surface water
Tin-113 (isotope)	1.37E-03	Bq	Output	Radioactivity	surface water
Tritium-3 (isotope)	4.41E+02	Bq	Output	Radioactivity	surface water
Xenon-131M (isotope)	4.54E-01	Bq	Output	Radioactivity	surface water
Xenon-133 (isotope)	6.97E+01	Bq	Output	Radioactivity	surface water
Xenon-133M (isotope)	5.71E-01	Bq	Output	Radioactivity	surface water
Xenon-135 (isotope)	5.20E-01	Bq	Output	Radioactivity	surface water

Table 3a. U.S. Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Zinc-85 (isotope)	6.65E-04	Bq	Output	Radioactivity	surface water

Table 3b. Japanese Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
PRIMARY INPUTS					
Coal, avg. (in ground)	8.88E+01	G	Input	Primary material	
Natural gas	4.85E+01	G	Input	Primary material	
Petroleum (in ground)	5.00E+01	G	Input	Primary material	
Uranium, yellowcake	1.18E-02	G	Input	Primary material	
ANCILLARY INPUTS					
Lime	5.24E-01	G	Input	Ancillary material	
Limestone	1.19E+00	G	Input	Ancillary material	
Water	1.72E+03	G	Input	Water	
PRODUCT					
Electricity	1.00E+00	KWH	Output	Energy	
AIR EMISSIONS					
1,1,1-Trichloroethane	2.51E-06	G	Output	Airborne	air
1,2-Dichloroethane	1.78E-06	G	Output	Airborne	air
2,3,7,8-TCDD	6.53E-13	G	Output	Airborne	air
2,3,7,8-TCDF	2.27E-12	G	Output	Airborne	air
2,4-Dinitrotoluene	1.24E-08	G	Output	Airborne	air
2-Chloroacetophenone	3.11E-07	G	Output	Airborne	air
2-Methylnaphthalene	9.24E-09	G	Output	Airborne	air
5-Methyl chrysene	9.77E-10	G	Output	Airborne	air
Acenaphthene	1.68E-07	G	Output	Airborne	air
Acenaphthylene	1.28E-08	G	Output	Airborne	air
Acetaldehyde	2.53E-05	G	Output	Airborne	air
Acetophenone	6.66E-07	G	Output	Airborne	air
Acrolein	1.29E-05	G	Output	Airborne	air
Anthracene	1.77E-08	G	Output	Airborne	air
Antimony	3.69E-05	G	Output	Airborne	air
Arsenic	2.72E-05	G	Output	Airborne	air
Barium	2.01E-05	G	Output	Airborne	air
Benzene	5.92E-05	G	Output	Airborne	air
Benzo[a]anthracene	3.11E-08	G	Output	Airborne	air
Benzo[a]pyrene	1.69E-09	G	Output	Airborne	air
Benzo[b,j,k]fluoranthene	1.51E-08	G	Output	Airborne	air
Benzo[g,h,i]perylene	1.67E-08	G	Output	Airborne	air
Benzyl chloride	3.11E-05	G	Output	Airborne	air
Beryllium	1.26E-06	G	Output	Airborne	air

Table 3b. Japanese Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Biphenyl	7.55E-08	G	Output	Airborne	air
Bromoform	1.73E-06	G	Output	Airborne	air
Bromomethane	7.11E-06	G	Output	Airborne	air
Cadmium	5.48E-06	G	Output	Airborne	air
Carbon dioxide	5.98E+02	G	Output	Airborne	air
Carbon disulfide	5.78E-06	G	Output	Airborne	air
Carbon monoxide	1.09E-01	G	Output	Airborne	air
Chloride ions	2.39E-03	G	Output	Airborne	air
Chlorobenzene	9.77E-07	G	Output	Airborne	air
Chloroform	2.62E-06	G	Output	Airborne	air
Chromium (III)	2.15E-05	G	Output	Airborne	air
Chromium (VI)	5.22E-06	G	Output	Airborne	air
Chrysene	2.08E-08	G	Output	Airborne	air
Cobalt	4.60E-05	G	Output	Airborne	air
Copper	1.24E-05	G	Output	Airborne	air
Cumene hydroperoxide	2.35E-07	G	Output	Airborne	air
Cyanide (-1)	1.11E-04	G	Output	Airborne	air
Di(2-ethylhexyl)phthalate	3.24E-06	G	Output	Airborne	air
Dibenzo[a,h]anthracene	1.15E-08	G	Output	Airborne	air
Dichloromethane	1.29E-05	G	Output	Airborne	air
Dimethyl sulfate	2.13E-06	G	Output	Airborne	air
Dioxins, remaining unspeciated	2.90E-11	G	Output	Airborne	air
Ethyl Chloride	1.87E-06	G	Output	Airborne	air
Ethylbenzene	4.61E-06	G	Output	Airborne	air
Ethylene dibromide	5.33E-08	G	Output	Airborne	air
Fluoranthene	6.79E-08	G	Output	Airborne	air
Fluorene	7.11E-08	G	Output	Airborne	air
Fluorides (F-)	2.57E-04	G	Output	Airborne	air
Formaldehyde	3.97E-04	G	Output	Airborne	air
Furans, remaining unspeciated	4.62E-11	G	Output	Airborne	air
Hexane	2.98E-06	G	Output	Airborne	air
Hydrochloric acid	5.33E-02	G	Output	Airborne	air
Hydrofluoric acid	6.66E-03	G	Output	Airborne	air
Indeno(1,2,3-cd)pyrene	1.74E-08	G	Output	Airborne	air
Isophorone	2.58E-05	G	Output	Airborne	air
Lead (Pb, ore)	1.71E-05	G	Output	Airborne	air
Magnesium	4.89E-04	G	Output	Airborne	air
Manganese (Mn, ore)	4.24E-05	G	Output	Airborne	air
Mercury	4.59E-06	G	Output	Airborne	air

Table 3b. Japanese Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Methane	3.16E-03	G	Output	Airborne	air
Methyl chloride	2.35E-05	G	Output	Airborne	air
Methyl ethyl ketone	1.73E-05	G	Output	Airborne	air
Methyl hydrazine	7.55E-06	G	Output	Airborne	air
Methyl methacrylate	8.88E-07	G	Output	Airborne	air
Methyl tert-butyl ether	1.55E-06	G	Output	Airborne	air
Molybdenum	6.01E-06	G	Output	Airborne	air
Naphthalene	8.60E-06	G	Output	Airborne	air
Nickel	5.72E-04	G	Output	Airborne	air
Nitrogen oxides	1.58E+00	G	Output	Airborne	air
Nitrous oxide	4.34E-03	G	Output	Airborne	air
o-xylene	7.50E-07	G	Output	Airborne	air
Phenanthrene	2.02E-07	G	Output	Airborne	air
Phenol	7.11E-07	G	Output	Airborne	air
PM-10	7.77E-02	G	Output	Airborne	air
Propionaldehyde	1.69E-05	G	Output	Airborne	air
Pyrene	4.90E-08	G	Output	Airborne	air
Selenium	6.25E-05	G	Output	Airborne	air
Styrene	1.11E-06	G	Output	Airborne	air
Sulfur dioxide	3.35E+00	G	Output	Airborne	air
Tetrachloroethylene	1.91E-06	G	Output	Airborne	air
TOCs, remaining unspeciated	7.66E-03	G	Output	Airborne	air
Toluene	5.56E-05	G	Output	Airborne	air
Vanadium	2.22E-04	G	Output	Airborne	air
Vinyl acetate	3.37E-07	G	Output	Airborne	air
Xylene (mixed isomers)	1.64E-06	G	Output	Airborne	air
Zinc (elemental)	2.00E-04	G	Output	Airborne	air
WATER RELEASES					
Sulfate ion (-4)	3.39E-02	G	Output	Waterborne	surface water
Suspended solids	8.82E-04	G	Output	Waterborne	surface water
WASTE					
Coal waste	2.52E+01	G	Output	Solid waste	landfill
Dust/sludge	9.73E+00	G	Output	Solid waste	landfill
Fly/bottom ash	6.30E+00	G	Output	Solid waste	landfill
Low-level radioactive waste	4.29E-03	G	Output	Radioactive waste	landfill
Uranium, depleted	1.29E-03	G	Output	Radioactive waste	landfill
RADIOACTIVE AIR EMISSIONS					
Argon-41 (isotope)	3.89E+01	Bq	Output	Radioactivity	air
Bromine-89 (isotope)	4.50E-06	Bq	Output	Radioactivity	air

Table 3b. Japanese Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Bromine-90 (isotope)	1.83E-06	Bq	Output	Radioactivity	air
Cesium-134 (isotope)	1.24E-04	Bq	Output	Radioactivity	air
Cesium-137 (isotope)	9.33E-04	Bq	Output	Radioactivity	air
Chromium-51 (isotope)	2.44E-03	Bq	Output	Radioactivity	air
Cobalt-57 (isotope)	6.57E-06	Bq	Output	Radioactivity	air
Cobalt-58 (isotope)	8.38E-05	Bq	Output	Radioactivity	air
Cobalt-60 (isotope)	6.31E-04	Bq	Output	Radioactivity	air
Iodine-131 (isotope)	2.95E-03	Bq	Output	Radioactivity	air
Iodine-132 (isotope)	5.99E-04	Bq	Output	Radioactivity	air
Iodine-133 (isotope)	2.73E+00	Bq	Output	Radioactivity	air
Iodine-134 (isotope)	3.10E-03	Bq	Output	Radioactivity	air
Iodine-135 (isotope)	1.56E-04	Bq	Output	Radioactivity	air
Krypton-85 (isotope)	6.46E+01	Bq	Output	Radioactivity	air
Krypton-85M (isotope)	3.13E+00	Bq	Output	Radioactivity	air
Krypton-87 (isotope)	1.17E+00	Bq	Output	Radioactivity	air
Krypton-88 (isotope)	5.47E+00	Bq	Output	Radioactivity	air
Manganese-54 (isotope)	3.47E-05	Bq	Output	Radioactivity	air
Niobium-95 (isotope)	1.38E-06	Bq	Output	Radioactivity	air
Rubidium-88 (isotope)	1.28E-02	Bq	Output	Radioactivity	air
Silver-110M (isotope)	4.11E-08	Bq	Output	Radioactivity	air
Technetium-99M (isotope)	1.85E-07	Bq	Output	Radioactivity	air
Tritium-3 (isotope)	9.13E+01	Bq	Output	Radioactivity	air
Xenon-131M (isotope)	5.27E+00	Bq	Output	Radioactivity	air
Xenon-133 (isotope)	5.05E+01	Bq	Output	Radioactivity	air
Xenon-133 (isotope)	5.05E+01	Bq	Output	Radioactivity	air
Xenon-133M (isotope)	7.60E+02	Bq	Output	Radioactivity	air
Xenon-135 (isotope)	2.87E+01	Bq	Output	Radioactivity	air
Xenon-135M (isotope)	5.48E-01	Bq	Output	Radioactivity	air
Xenon-138 (isotope)	1.82E+00	Bq	Output	Radioactivity	air
Zirconium-95 (isotope)	3.56E-06	Bq	Output	Radioactivity	air
RADIOACTIVE WATER RELEASES					
Antimony-124 (isotope)	1.92E-02	Bq	Output	Radioactivity	surface water
Antimony-125 (isotope)	7.67E-02	Bq	Output	Radioactivity	surface water
Barium-140 (isotope)	1.43E-03	Bq	Output	Radioactivity	surface water
Cesium-134 (isotope)	5.15E-02	Bq	Output	Radioactivity	surface water
Cessium-137 (isotope	7.73E-02	Bq	Output	Radioactivity	surface water
Chromium-51 (isotope)	9.27E-02	Bq	Output	Radioactivity	surface water
Cobalt-57 (isotope)	2.24E-03	Bq	Output	Radioactivity	surface water
Cobalt-58 (isotope)	9.13E-01	Bq	Output	Radioactivity	surface water

Table 3b. Japanese Electricity Generation Inventory [inputs and outputs per kWh (3.6 MJ)]

Material	Quantity	Units	Input/output	Input/output type	Disposition
Cobalt-80 (isotope)	2.40E-01	Bq	Output	Radioactivity	surface water
Iodine-131 (isotope)	4.28E-02	Bq	Output	Radioactivity	surface water
Iodine-132 (isotope)	1.62E-02	Bq	Output	Radioactivity	surface water
Iodine-133 (isotope)	1.83E-02	Bq	Output	Radioactivity	surface water
Iodine-135 (isotope)	1.31E-02	Bq	Output	Radioactivity	surface water
Iron-55 (isotope)	2.18E-01	Bq	Output	Radioactivity	surface water
Iron-59 (isotope)	1.12E-02	Bq	Output	Radioactivity	surface water
Krypton-85M (isotope)	5.77E-02	Bq	Output	Radioactivity	surface water
Lanthanum-140 (isotope)	1.53E-03	Bq	Output	Radioactivity	surface water
Manganese-54 (isotope)	6.11E-02	Bq	Output	Radioactivity	surface water
Molybdenum-99 (isotope)	1.15E+05	Bq	Output	Radioactivity	surface water
Niobium-95 (isotope)	1.57E-02	Bq	Output	Radioactivity	surface water
Ruthenium-103 (isotope)	1.92E-03	Bq	Output	Radioactivity	surface water
Silver-110M (isotope)	2.24E-02	Bq	Output	Radioactivity	surface water
Sodium-24 (isotope)	3.42E-03	Bq	Output	Radioactivity	surface water
Strontium-89 (isotope)	3.70E-03	Bq	Output	Radioactivity	surface water
Strontium-90 (isotope)	8.69E-04	Bq	Output	Radioactivity	surface water
Strontium-95 (isotope)	9.57E-03	Bq	Output	Radioactivity	surface water
Sulfur-136 (isotope)	2.06E-03	Bq	Output	Radioactivity	surface water
Technetium-99M (isotope)	1.34E-03	Bq	Output	Radioactivity	surface water
Tin-113 (isotope)	2.12E-03	Bq	Output	Radioactivity	surface water
Tritium-3 (isotope)	6.83E+02	Bq	Output	Radioactivity	surface water
Xenon-131M (isotope)	7.02E-01	Bq	Output	Radioactivity	surface water
Xenon-133M (isotope)	8.84E-01	Bq	Output	Radioactivity	surface water
Xenon-135 (isotope)	8.05E-01	Bq	Output	Radioactivity	surface water
Zinc-85 (isotope)	1.03E-03	Bq	Output	Radioactivity	surface water

3. METHODOLOGY

The U.S.-wide inventory was developed by first compiling inventory data for each of the major generation (fuel-specific) categories used to produce electricity in the U.S., and then creating the U.S.-wide inventory from the fuel-specific inventories. The creation of the U.S.-wide data from the fuel-specific inventories required two particular sets of information: 1997 fuel consumption data and 1997 fuel-specific net electricity generation data (see Table 4). In the majority of cases, one or more pieces of information from these two data sets was needed to convert each input or output into the units of grams per kWh (excluding the radionuclides which were converted to Becquerels per kWh).

Table 4. 1997 U.S. Electricity Utility Summary Statistics

Fuel [a]	1997 Fuel Consumption	Units	1997 Net Electricity Generation	1997 Generation % Breakdown
Coal	900,361,000	short tons/yr	1,787,806,000,000	57.23%
Gas	2,968,453	million ft3/yr	283,625,000,000	9.07%
Petroleum	5,256,132	thousand gal/yr	77,753,000,000	2.53%
Nuclear	48,700,000	lbs U_3O_8/yr	628,644,000,000	20.14%
Hydro [b]	--	--	337,233,000,000	10.79%
Renewables [b]	--	--	7,462,000,000	0.24%
Total			3,122,522,000,000	100%

Source: EIA 1999a.
[a] This breakdown exludes nonutility electricity genration (non and Independent Power Producers (NPPs or IPPs), which typically contribute about 11% of the U.S. total (EIA 1999).
[b] Hydro and renewables were exluded from the calculation of inputs and outputs.

Data on the inputs and outputs for electricity generation were obtained from available sources; when multiple sources of the same type of data were found, those data believed to have the highest quality were utilized (Section 5 addresses data quality). Most data obtained were fuel-specific, however some of the data found were already aggregated to the U.S.-wide level, and thus did not need converting from the fuel-specific values. Thus, for some input/output categories, few calculations were necessary; for others, more complex equations were required to calculate the final input or output data.

As stated earlier in this TM, the final electric grid inventory data (in units of grams/net kWh, for example) will be multiplied by energy use values throughout the life cycle (in units of point-of-use kWhs/functional unit). The two kWhs referred to are different, with the difference being net generated kWhs versus point-of-use kWhs. Due to losses that are associated with moving electrical energy from a point of generation to a point of use, known as ‘transmission and distribution (TD) losses,’ these must be accounted for in the calculations. It was found in the research for this TM that for 1997 the nationwide TD losses were on the order of 8% of net generation (EIA 1999b). Therefore, to make the kWhs equivalent, the net generation was divided by a TD factor of 1.08 to effectively convert the net kWhs to point-of-use kWhs. The net kWhs are divided by the 1.08 TD factor in all the equations shown in this TM.

The following subsections provide the methodology used and basic equations utilized to create the U.S.-wide inventory from the fuel-specific input and output values.

3.1 Inputs

3.1.1 Primary Materials

Primary materials are typically considered in LCA to be those materials that become part of the final product of the process being modeled. For the process of electricity generation, the fuels used to produce the electrical energy are usually considered to be the only 'primary' materials. Thus, for the U.S. and Japanese electric grid inventory data, the primary materials include coal, gas, petroleum and uranium. The U.S. nationwide total quantities of these fuels consumed by utilities in 1997 was obtained from the Energy Information Administration (EIA 1999a for coal, gas and petroleum; EIA 1998b for uranium). The Japanese data were obtained from the EIA's Country Energy Data Report (EIA 1997). Note that the primary material for nuclear-based electricity generation is referred to as "yellowcake," which is the most common physical state on which uranium consumption is based. Yellowcake is a yellowish-brown powder that is the product of the initial milling process that follows mining. The input data were provided on a nationwide basis, thus the equation needed to calculate each fuel's use rate in grams per kWh is shown below:

$$UR_{fuel\ i} = \frac{Con_{fuel\ i}}{\dfrac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 1}}$$

where,

$UR_{fuel\ i}$	=	nationwide input use rate per unit of electricity for fuel *i*, where the four fuels are coal, gas, petroleum and uranium (grams/kWh),
$Con_{fuel\ i}$	=	annual consumption rate for fuel *i* (mass or volume/yr; converted to grams using density as necessary, see Attachment E, Table E5),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

In calculating the primary material consumption rates for each fuel, material densities and conversion factors for mass, volume and energy were utilized where needed, depending on whether the units of consumption were in mass or volume (see Attachment E, Table E5).

3.1.2 Ancillary Materials

Ancillary materials are considered to be those materials that help the process function or work, yet do not become part of the final product. In generating electricity, all materials used, except the fuel itself, are typically considered to be ancillary materials. The ancillary materials accounted for in the U.S. electric grid inventory data are limestone and lime which are sulfur dioxide removal system catalysts typically used in coal firing, and cooling water which is consumed in generating electricity from all fuel types.

The limestone and lime values were derived by utilizing data from approximately five different sources, primarily the EIA, the Acid Rain database and direct contact with utility employees. In short, individual lime and limestone annual consumption rates were developed in units of pounds per year for each plant in the U.S. that utilizes a lime- or limestone-based flue gas desulfurization (FGD) system, and then those values were added to obtain the total poundage or tonnage consumed annually in the U.S. (tons per year). At that point, Equation 1 could be used (calculating only for coal) to obtain the quantity of lime or limestone consumed in grams per kWh generated. Cooling water consumption in units of gallons per kWh was obtained from the California Energy Commission (CEC 1979; cited in Paul Gipe's *Wind Energy Comes of Age*, John Wiley & Sons, 1995). Since cooling water is consumed during electricity generation for each of the fuel types followed in this inventory data set, one equation was used to calculate the nationwide average cooling water requirements:

$$UR_{water} = \frac{\sum_{i=1}^{4} \left(Con_{water} \times Gen\right)_{fuel\ i}}{\dfrac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 2}}$$

where,

Ur_{water}	=	nationwide input use rate per unit of electricity for water (grams/kWh),
Con_{water}	=	average consumption rate per unit of electricity for water for fuel *i*, where the four fuels are coal, gas, petroleum and uranium (gallons/kWh; converted to grams using density, see Attachment E, Table E5),
Gen	=	net annual electricity generation rate for fuel *i* (kWh/yr),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

3.2 Outputs

3.2.1 Air Emissions

Several sources of air emissions data where evaluated in compiling the electric grid inventory data. The evaluation revealed that AP-42 (EPA 1996) data are the most complete source of speciated air emissions data *that are easily accessible and do not require a substantial investment to obtain*. Thus, AP-42 data were used as the foundation for the air emissions estimates. ('AP-42' is the EPA's emission factors data set that addresses the type and quantity of air pollutants that result from over 200 major industries, point sources and mobile sources.)

The evaluation also revealed a few sources of higher quality data for some pollutants, and in those cases, that information was used to either augment or replace the AP-42 factors. Specifically, the air pollutant release rates for criteria pollutants were obtained from the EPA (1998b) on a nationwide annual basis and used instead of the AP-42 factors for those pollutants (the values covered all fossil fuel-based generation categories and were in units of pounds per year). The criteria pollutants include carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides

(NO_X), carbon monoxide (CO), lead (Pb) and particulate matter ten micrometers or less in diameter (PM-10), and the following equation was used to obtain the emission rates for these pollutants in units of grams/kWh:

$$RR_{air-criteria\ i} = \frac{Rel_{air-criteria\ i}}{\frac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 3}}$$

where,

$RR_{air\text{-}criteria\ i}$	=	nationwide release rate per unit of electricity for criteria pollutant *i* (grams/kWh),
$Rel_{air\text{-}criteria\ i}$	=	annual release rate for criteria pollutant *i* (lbs/yr),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

Nuclear power plants produce electricity without combusting fuel, thus no criteria pollutants are emitted to the local air environment during nuclear power production. However, nuclear-based electricity generation does produce some airborne radionuclides, which are addressed in Section 3.2.4. No airborne releases from nuclear-based generation are addressed here.

The air pollutants accounted for in this inventory calculated from AP-42 air emission factors are shown in Table 5. Of these air emission factors, Table 5 shows the number of pollutants in each category, what fuels AP-42 has release data for, and whether the AP-42 data reflects controlled or uncontrolled release of those pollutants.

The equation used to calculate the nationwide emissions of these non-criteria pollutants is Equation 4. The equation shows a summation of three release and consumption rates, which was adjusted for the number of fuels from which the pollutants were listed in AP-42 (shown in Table 5).

For all of the pollutants in Table 5, AP-42 lists only one emission factor per pollutant per fuel (for example, pounds of benzene released per ton of coal burned). Thus, each factor represents a combined emissions estimate for the various technologies used to fire each fuel.

In augmenting the AP-42 data, it was also determined that the nationwide methane (CH_4) air releases generated during coal mining (EPA 1998c) are significant, and were added to the emissions estimates of CH_4 from coal and petroleum combustion. These emissions were presented in units of nationwide cubic feet of methane released per year.

Table 5. Air Pollutant Information from AP-42

Pollutant Category/Pollutant	# of factors provided	Fuels from Which Pollutants Were Listed in AP-42			Controlled/ Uncontrolled
		Coal	Gas	Petroleum	
Speciated organic compounds	37	✔	✔	✔	Controlled
Trace metals	13	✔	✔	✔	Controlled
Polycryclic aromatic hydrocarbons	16	✔			Controlled
Dioxins & furans	16	✔			Controlled
Methane	1	✔		✔	Uncontrolled
Nitrous oxide	1	✔	✔	✔	Uncontrolled
Hydrogen chloride	1	✔			Uncontrolled
Hydrogen fluoride	1	✔			Uncontrolled
Total organic compounds	1	✔	✔	✔	Uncontrolled
Total nonmethane organic compounds	1	✔		✔	Uncontrolled

Source: EPA 1996.

$$RR_{air-other\ j} = \frac{\sum_{i=1}^{3}\left(Rel_{air-other\ j} \times Con\right)_{fuel\ i}}{\dfrac{Gen_{net}}{TD}} \qquad Eq.\ 4$$

where,

$Rr_{air\text{-}other\ j}$ = nationwide release rate for each pollutant *j* (grams/kWh),

$Rel_{air\text{-}other\ j}$ = release rate per unit of fuel for each air pollutant *j* from fossil fuel *i* (coal - lbs/ton, gas - lbs/million cubic feet, petroleum - lbs/thousand gallons),

Con = annual consumption rate of fuel *i* (coal - tons/yr, gas - million cubic feet/yr, petroleum - thousand gallons/yr),

Gen_{net} = net annual nationwide electricity generation (kWh/yr), and

TD = nationwide average transmission and distribution losses factor (percent).

3.2.2 Solid Wastes

For the U.S. electric grid inventory data, two types of solid waste exist: coal-fired generation nonhazardous solid wastes and nuclear-based generation radioactive solid wastes. [The term 'solid waste' as it is used in this report applies to the Resource Conservation and Recovery Act (RCRA) definition which is defined in the U.S. Federal Code of Regulations (40 CFR 261).] For coal-fired generation, the solid wastes values were obtained from a 1994 Oak Ridge National Laboratory (ORNL) report entitled "Estimating Externalities of Coal Fuel Cycles," and were provided in units of tons of waste produced per gigawatthour (GWh) generated. The calculation needed to obtain the nationwide releases is as follows:

$$RR_{solid\ i} = \frac{Rel_{solid\ i} \times Gen_{coal}}{\frac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 5}}$$

where,

$RR_{solid\ i}$	=	nationwide release rate per unit of electricity for solid waste *i* from coal-fired generation (grams/kWh),
$Rel_{solid\ i}$	=	release rate per unit of electricity for solid waste *i* from coal-fired generation (tons/GWh),
Gen_{coal}	=	net annual electricity generation rate for coal (MWh/yr),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

For the two nuclear-based generation wastes quantified, spent fuel and low-level radioactive waste (LLRW), two data sources were utilized. The spent fuel data information was obtained from the EIA in units of pounds per year and the LLRW data from an expert in the nuclear electricity generation industry (Loiselle 1998) in units of cubic feet per year (see Attachment E, Table E5 for LLRW conversion factor). The calculation used to derive the quantity of both nuclear wastes generated in units of grams per kWh was similar to Equations 1 and 3, and is shown below:

$$GR_{nuclear\ i} = \frac{Gen_{nuclear\ i}}{\frac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 6}}$$

where,

$GR_{nuclear\ i}$	=	nationwide generation rate per unit of electricity for nuclear waste *i* (grams/kWh),
$Gen_{nuclear\ i}$	=	nationwide annual generation rate for nuclear waste *i* (spent fuel - lbs/yr, LLRW - ft^3/yr; converted to grams using density as necessary, see Attachment E, Table E5),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

3.2.3 Water Releases

Water release information was obtained on coal-fired generation. Radioactive water release information is presented in Section 3.2.4. Information on only three water pollutants was obtained (ORNL 1994). Data were in units of tons/GWh, and thus used an equation like Equation 5 to calculate the nationwide release per unit of electricity generated:

$$RR_{water\ i} = \frac{Rel_{water\ i} \times Gen_{coal}}{\frac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 7}}$$

where,

$RR_{water\ i}$	=	nationwide release rate per unit of electricity for water pollutant *i* from coal-fired generation (grams/kWh),
$Rel_{water\ i}$	=	release rate per unit of electricity for water pollutant *i* from coal-fired generation (tons/GWh),
Gen_{coal}	=	net annual electricity generation rate for coal (MWh/yr),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

3.2.4 Radionuclides

During the operation of nuclear electricity generation facilities, both airborne and waterborne radioactive releases are generated that are not directly related to a facility's capacity to generate power (kWs) or to the quantity of power it generates over time (kWhs). Data were obtained on the radioactive releases of many nuclear facilities in the U.S. from an ORNL report which addressed the externalities of nuclear fuel cycles (ORNL 1995). This report presented averaged release rate information for 31 airborne and 35 waterborne radioactive releases, which were from direct measurements at many U.S.-based nuclear facilities, all of which were presented in units of Curies per year. Although the releases where found *not* to relate directly to power generation or power generating capacity, some scale was needed to convert the quantity of release from multiple facilities to a quantity of release for all the facilities in use in the U.S. Therefore, due to a lack of any other identifiable scaling mechanism, the quantity of power generated was utilized. The Curies per year value for each radioactive release was first converted into Curies per MWh by dividing by the number of MWhs generated by the average facility identified in the report. Then the values were converted into units of Becquerels per kWh. The following equation was utilized for converting airborne and waterborne radionuclides to the nationwide grid:

$$RR_{radionuclide\ i} = \frac{Rel_{radionuclide\ i} \times Gen_{nuclear}}{\frac{Gen_{net}}{TD}} \qquad \textbf{\textit{Eq. 8}}$$

where,

$RR_{radionuclide\ i}$	=	nationwide release rate per unit of electricity for radionuclide *i* (Becquerels/kWh),
$Rel_{radionuclide\ i}$	=	averaged release rate per unit of electricity for radionuclide *i* (Curies/MWh),
$Gen_{nuclear}$	=	annual electricity generation rate for nuclear (MWh/yr),
Gen_{net}	=	net annual nationwide electricity generation (kWh/yr), and
TD	=	nationwide average transmission and distribution losses factor (percent).

4. FUEL-SPECIFIC RESULTS

Tables 6 through 9 present the inputs and outputs from each of the individual fuel inventories. The data in those tables were aggregated into the U.S.-wide average data for electricity generation (Table 3a) and Japanese average data (Table 3b). Additionally, the spreadsheets from which Tables 6 through 9 were derived are shown in Attachments A through E and provide some additional information about each inventory.

Table 6. Inputs and Outputs for Coal-Fired Electricity Generation in the United States[a]

Material/pollutant	Quantity	Unit
INPUTS		
Primary Materials		
Coal	9.00E+08	tons/yr
Ancillary Materials		
Limestone	1.21E+07	tons/yr
Lime	5.31E+06	tons/yr
Cooling water	4.90E-01	gal/kWh
OUTPUTS		
Air Emissions		
Methane	4.00E-02	lbs/ton
Nitrous oxide	3.00E-02	lbs/ton
Hydrogen chloride	1.20E+00	lbs/ton
Hydrogen fluoride	1.50E-01	lbs/ton
TOC	3.00E-01	lbs/ton
TNMOC	6.00E-02	lbs/ton
SPECIATED ORGANIC COMPOUNDS		
Acetaldehyde	5.70E-04	lbs/ton
Acetophenone	1.50E-05	lbs/ton
Acrolein	2.90E-04	lbs/ton
Benzene	1.30E-03	lbs/ton
Benzyl chloride	7.00E-04	lbs/ton
Bis(2-ethylhexyl)phthalate (DEHP)	7.30E-05	lbs/ton
Bromoform	3.90E-05	lbs/ton
Carbon disulfide	1.30E-04	lbs/ton
2-Chloroacetophenone	7.00E-06	lbs/ton
Chlorobenzene	2.20E-05	lbs/ton
Chloroform	5.90E-05	lbs/ton
Cumene	5.30E-06	lbs/ton
Cyanide	2.50E-03	lbs/ton
2,4-Dinitrotoluene	2.80E-07	lbs/ton
Dimethyl sulfate	4.80E-05	lbs/ton
Ethyl benzene	9.40E-05	lbs/ton

Material/pollutant	Quantity	Unit
OUTPUTS (continued)		
Air Emissions (continued)		
TRACE METALS (continued)		
Beryllium	2.10E-05	lbs/ton
Cadmium	5.10E-05	lbs/ton
Chromium	2.60E-04	lbs/ton
Chromium (VI)	7.90E-05	lbs/ton
Cobalt	1.00E-04	lbs/ton
Magnesium	1.10E-02	lbs/ton
Manganese	4.90E-04	lbs/ton
Mercury	8.30E-05	lbs/ton
Nickel	2.80E-04	lbs/ton
Selenium	1.30E-03	lbs/ton
POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)		
Biphenyl	1.70E-06	lbs/ton
Acenaphthene	5.10E-07	lbs/ton
Acenaphthylene	2.50E-07	lbs/ton
Anthracene	2.10E-07	lbs/ton
Benzo(a)anthracene	8.00E-08	lbs/ton
Benzo(a)pyrene	3.80E-08	lbs/ton
Benzo(b,j,k)fluoranthene	1.10E-07	lbs/ton
Benzo(g,h,i)perylene	2.70E-08	lbs/ton
Chrysene	1.00E-07	lbs/ton
Fluoranthene	7.10E-07	lbs/ton
Fluorene	9.10E-07	lbs/ton
Indeno(1,2,3-cd)pyrene	6.10E-08	lbs/ton
Naphthalene	1.30E-05	lbs/ton
Phenanthrene	2.70E-06	lbs/ton
Pyrene	3.30E-07	lbs/ton
5-Methyl chrysene	2.20E-08	lbs/ton
DIOXINS & FURANS		
2,3,7,8-TCDD	1.43E-11	lbs/ton
Total TCDD	9.28E-11	lbs/ton
Total PeCDD	4.47E-11	lbs/ton

Table 6. Inputs and Outputs for Coal-Fired Electricity Generation in the United States[a]

Material/pollutant	Quantity	Unit		Material/pollutant	Quantity	Unit
Ethyl chloride	4.20E-05	lbs/ton		Total HxCDD	2.87E-11	lbs/ton
Ethylene dichloride	4.00E-05	lbs/ton		Total HpCDD	8.34E-11	lbs/ton
Ethylene dibromide	1.20E-06	lbs/ton		Total OCDD	4.16E-10	lbs/ton
Formaldehyde	2.40E-04	lbs/ton		Total PCDDd	6.66E-10	lbs/ton
Hexane	6.70E-05	lbs/ton		2,3,7,8-TCDF	5.10E-11	lbs/ton
Isophorone	5.80E-04	lbs/ton		Total TCDF	4.04E-10	lbs/ton
Methyl bromide	1.60E-04	lbs/ton		Total PeCDF	3.53E-10	lbs/ton
Methyl chloride	5.30E-04	lbs/ton		Total HxCDF	1.92E-10	lbs/ton
Methyl ethyl ketone	3.90E-04	lbs/ton		Total HpCDF	7.68E-11	lbs/ton
Methyl hydrazine	1.70E-04	lbs/ton		Total OCDF	6.63E-11	lbs/ton
Methyl methacrylate	2.00E-05	lbs/ton		Total PCDFd	1.09E-09	lbs/ton
Methyl tert butyl ether	3.50E-05	lbs/ton		*COAL MINE METHANE EMISSIONS*		
Methylene chloride	2.90E-04	lbs/ton		Methane	1.52E+11	ft^3/yr
Phenol	1.60E-05	lbs/ton				
Propionaldehyde	3.80E-04	lbs/ton		**Solid Wastes**		
Tetrachloroethylene	4.30E-05	lbs/ton		Dust/sludge	5.51E+01	tons/GWh
Toluene	2.40E-04	lbs/ton		Coal waste	1.43E+02	tons/GWh
1,1,1-Trichloroethane	2.00E-05	lbs/ton		Fly/bottom ash	3.57E+01	tons/GWh
Styrene	2.50E-05	lbs/ton				
Xylenes	3.70E-05	lbs/ton		**Water Releases**		
Vinyl acetate	7.60E-06	lbs/ton		Dissolver	2.78E-01	tons/GWh
TRACE METALS				Suspended solids	5.00E-03	tons/GWh
Antimony	1.80E-05	lbs/ton		Sulfate	1.92E-01	tons/GWh

[a] All inputs and outputs have been left in their original units of measure.

Table 7. Inputs and Outputs for Gas-Fired Electricity Generation in the United States

Material/pollutant	Quantity	Unit
INPUTS		
Primary Material		
Gas	3.00E+12	yr 3/yr
Ancillary Material		
Water	2.50E-01	gal/kWh
OUTPUTS		
Air Emissions		
Nitrous oxide	2.20E+00	lbs/Mft3
Filterable PM	1.50E+00	lbs/Mft3
Condensible PM	1.50E+00	lbs/Mft3
TOC	1.70E+00	lbs/Mft3
SPECIATED ORGANIC COMPOUNDS		
Fluoranthene	3.01E-06	lbs/Mft3
Formaldehyde	1.55E-01	lbs/Mft3
2-Methylnaphthalene	9.02E-06	lbs/Mft3

Pollutant	Quantity	Unit
OUTPUTS (continued)		
Air Emissions (continued)		
SPECIATED ORGANIC COMPOUNDS (continued)		
Naphthalene	2.40E-04	lbs/Mft3
Phenanthrene	1.00E-05	lbs/Mft3
Pyrene	5.01E-06	lbs/Mft3
Toluene	2.20E-03	lbs/Mft3
TRACE METALS		
Arsenic	2.30E-04	lbs/Mft3
Barium	2.40E-03	lbs/Mft3
Chromium	1.10E-03	lbs/Mft3
Cobalt	1.20E-04	lbs/Mft3
Copper	2.51E-04	lbs/Mft3
Manganese	3.81E-04	lbs/Mft3
Molybdenum	5.81E-04	lbs/Mft3
Nickel	3.61E-03	lbs/Mft3
Vanadium	3.21E-03	lbs/Mft3

[a] All inputs and outputs have been left in their original units of measure.

Table 8. Inputs and Outputs for Petroleum-Fired Electricity Generation in the U.S.

Material/Pollutant	Quantity	Unit
INPUTS		
Primary Material		
Petroleum		
Ancillary Material		
Water	4.30E-01	gal/kWh
OUTPUTS		
Air Emissions		
Methane	2.66E-01	lbs/kgal
Nitrous oxide	1.10E-01	lbs/kgal
TOC	9.93E-01	lbs/kgal
TNMOC	7.26E-01	lbs/kgal
SPECIATED ORGANIC COMPOUNDS		
Acenaphthene	2.11E-05	lbs/kgal
Acenaphthylene	2.53E-07	lbs/kgal
Anthracene	1.22E-06	lbs/kgal
Benzene	2.14E-04	lbs/kgal
Benz(a)anthracene	4.01E-06	lbs/kgal
Benzo(b,k)fluoranthene	1.48E-06	lbs/kgal
Benzo(g,h,i)perylene	2.26E-06	lbs/kgal

Pollutant	Quantity	Unit
OUTPUTS (continued)		
Air Emissions (continued		
SPECIATED ORGANIC COMPOUNDS (continued)		
OCDD	3.10E-09	lbs/kgal
Phenanthrene	1.05E-05	lbs/kgal
Pyrene	4.25E-06	lbs/kgal
Toluene	6.20E-03	lbs/kgal
1,1,1-Trichloroethane	2.36E-04	lbs/kgal
o-xylene	1.09E-04	lbs/kgal
TRACE METALS		
Antimony	5.25E-03	lbs/kgal
Arsenic	1.28E-03	lbs/kgal
Barium	2.57E-03	lbs/kgal
Beryllium	4.71E-05	lbs/kgal
Cadmium	4.67E-04	lbs/kgal
Chloride	3.47E-01	lbs/kgal
Chromium	1.28E-03	lbs/kgal
Chromium (VI)	2.48E-04	lbs/kgal
Cobalt	6.02E-03	lbs/kgal
Copper	1.76E-03	lbs/kgal
Fluoride	3.73E-02	lbs/kgal

Table 8. Inputs and Outputs for Petroleum-Fired Electricity Generation in the U.S.

Material/Pollutant	Quantity	Unit		Pollutant	Quantity	Unit
Chrysene	2.38E-06	lbs/kgal		Manganese	2.94E-03	lbs/kgal
Dibenzo(a,h)anthracene	1.67E-06	lbs/kgal		Mercury	1.31E-04	lbs/kgal
Ethylbenzene	6.36E-05	lbs/kgal		Molybdenum	7.87E-04	lbs/kgal
Fluoranthene	4.84E-06	lbs/kgal		Nickel	8.09E-02	lbs/kgal
Fluorene	4.47E-06	lbs/kgal		Phosphorous	9.46E-03	lbs/kgal
Formaldehyde	3.30E-02	lbs/kgal		Selenium	6.83E-04	lbs/kgal
Indo(1,2,3-cd)pyrene	2.14E-06	lbs/kgal		Vanadium	3.18E-02	lbs/kgal
Naphthalene	1.13E-03	lbs/kgal		Zinc	2.91E-02	lbs/kgal

[a] All inputs and outputs have been left in their original units of measure.

Table 9. Inputs and Outputs for Nuclear-Based Electricity Generation in the U.S.

Material/pollutant	Quantity	Unit		Pollutant	Quantity	Unit
INPUTS				**OUTPUTS** (continued)		
Primary Material				**Waterborne Radionuclide Emissions** (continued)		
Uranium oxide ("yellowcake")	4.87E+07	lbs/yr		Xe-135M	4.40E-08	Curies/MWh
				Cs-137	7.49E-11	Curies/MWh
Ancillary Material				Xe-138	1.46E-07	Curies/MWh
Water	6.20E-01	gal/kWh		**Waterborne Radionuclide Emissions**		
				T-3	5.48E-05	Curies/MWh
OUTPUTS				Na-24	2.75E-10	Curies/MWh
Solid Wastes				Cr-51	7.44E-09	Curies/MWh
Spent fuel	5.29E+06	lbs/yr		Mn-54	4.90E-09	Curies/MWh
LLRW	2.21E+05	ft^3/yr		Fe-55	1.75E-08	Curies/MWh
				Co-57	1.80E-10	Curies/MWh
Airborne Radionuclide Emissions				Co-58	7.33E-08	Curies/MWh
T-3	7.33E-06	Curies/MWh		Fe-59	9.00E-10	Curies/MWh
Ar-41	3.13E-06	Curies/MWh		Co-80	1.92E-08	Curies/MWh
Cr-51	1.96E-10	Curies/MWh		Zn-85	8.27E-11	Curies/MWh
Mn-54	2.78E-12	Curies/MWh		Kr-85M	4.63E-09	Curies/MWh
Co-57	5.27E-13	Curies/MWh		Sr-89	2.97E-10	Curies/MWh
Co-58	6.73E-12	Curies/MWh		Sr-90	6.97E-11	Curies/MWh
Co-60	5.06E-11	Curies/MWh		Nb-95	1.26E-09	Curies/MWh
Kr-85	5.18E-06	Curies/MWh		Sr-95	7.68E-10	Curies/MWh
Kr-85M	2.51E-07	Curies/MWh		Mo-99	9.25E-03	Curies/MWh
Kr-87	9.35E-08	Curies/MWh		Tc-99M	1.08E-10	Curies/MWh
Rb-88	1.03E-09	Curies/MWh		Ru-103	1.54E-10	Curies/MWh
Kr-88	4.39E-07	Curies/MWh		Ag-110M	1.80E-09	Curies/MWh
Br-89	3.62E-13	Curies/MWh		Sn-113	1.70E-10	Curies/MWh
Br-90	1.47E-13	Curies/MWh		Sb-124	1.54E-09	Curies/MWh
Nb-95	1.11E-13	Curies/MWh		Sb-125	6.15E-09	Curies/MWh
Zr-95	2.86E-13	Curies/MWh		I-131	3.43E-09	Curies/MWh
Tc-99M	1.48E-14	Curies/MWh		Xe-131M	5.64E-08	Curies/MWh

Table 9. Inputs and Outputs for Nuclear-Based Electricity Generation in the U.S.

Material/pollutant	Quantity	Unit		Pollutant	Quantity	Unit
Ag-110M	3.30E-15	Curies/MWh		I-132	1.30E-09	Curies/MWh
I-131	2.37E-10	Curies/MWh		Xe-133	8.66E-06	Curies/MWh
Xe-131M	4.23E-07	Curies/MWh		I-133	1.47E-09	Curies/MWh
I-132	4.80E-11	Curies/MWh		Xe-133M	7.10E-08	Curies/MWh
Xe-133	6.10E-05	Curies/MWh		Cs-134	4.13E-09	Curies/MWh
I-133	2.19E-07	Curies/MWh		I-135	1.06E-09	Curies/MWh
Xe-133M	4.06E-06	Curies/MWh		Xe-135	6.46E-08	Curies/MWh
Cs-134	9.93E-12	Curies/MWh		s-136	1.65E-10	Curies/MWh
I-134	2.49E-10	Curies/MWh		Cs-137	6.20E-09	Curies/MWh
Xe-135	2.30E-06	Curies/MWh		Ba-140	1.14E-10	Curies/MWh
I-135	1.25E-11	Curies/MWh		La-140	1.23E-10	Curies/MWh

[a] All inputs and outputs have been left in their original units of measure.

Table 10 presents the number of inventory data points for each fuel type by input or output category. As can easily be seen, most of the fuel-specific inventories are dominated by air pollution data. Of the main categories of air pollutants considered, the following breakdown lists those emissions that are the biggest contributors (have the largest emission rates in overall quantity) to each part of each fuel inventory:

- Coal – Cyanide (speciated organic compounds), magnesium (metal), naphthalene [polycyclic aromatic hydrocarbons (PAH)] and the total octochlorodibenzo-p-dioxins (dioxins and furans)
- Gas – Formaldehyde (speciated organic compound), nickel (metal)
- Petroleum – Formaldehyde (speciated organic compound), chloride (metal)
- Nuclear – Xenon-133 (airborne radionuclide), molybdenum-99 (waterborne radionuclide)

Note that in Tables 6 through 9, the units for the inputs and outputs were left as originally found in their source. All fuel-specific inputs and outputs (excluding radioactive releases) were converted to the units desired for the U.S.-wide electric grid of grams/kWh during aggregation into that inventory data set.

Table 10. Number of Inputs & Outputs Within Each Inventory

Inputs & Outputs	Coal	Gas	Petroleum	Nuclear
Primary materials	1	1	1	1
Ancillary materials	3	1	1	1
Air releases	89	29	51	31
Water releases	3	--	--	35
Solid & hazardous wastes	3	--	--	2
Total	99	31	53	70

5. DATA SOURCES & QUALITY

Source and quality information for the data presented in this TM are detailed in Table 11. In general, data assigned higher quality ratings were directly measured and represent 1997 data. As data required more calculation or estimation, or were from a previous year, data quality was reduced. Additional comments about data source and quality are in the following subsections.

5.1 Nonfuel specific data

The criteria pollutant air emission values used in this inventory all came from the *National Air Quality & Emissions Trends Report, 1997*. While this report does state that the values supplied are "estimates of the amount and kinds of pollutants being emitted … based upon best available engineering calculations," (EPA 1998b) the EPA used measured air emission rates where feasible, and thus these data were given ‘Average’ data quality ratings.

5.2 Coal

As the leading electricity-producing fuel in the U.S., coal has accounted for between 40% and 60% of the kWh produced by utilities in the national grid since the 1930s (NEI 1997). In 1997, coal-fired generation accounted for just over 57% of all utility-generated electricity.

Of the coal inventory data, the coal quantity used annually and the methane generated from coal mining were both directly measured data for 1997 and thus were given ‘Excellent’ data quality ratings. The data for speciated air emissions that came from AP-42 were deemed ‘Poor,’ due primarily to the following two facets of the data. First, in averaging the data quality ratings that the EPA applies to their AP-42 factors, an average rating of approximately 3 is calculated, indicating by their own standards an ‘average’ rating. (EPA’s data quality ratings are A, B, C, D and E, where, for example, A, C and E represent ‘Excellent,’ ‘Average’ and ‘Poor’ respectively. This alphabetically based system was temporarily converted into a numerical system of 1 through 5 where 1 corresponds to A and 5 corresponds to E to calculate the required averages.) Second, the bulk of the AP-42 data was dated January 1995; updates were included several times since then (two in 1996 and one in 1998), however, each update included only small changes to the whole AP-42 emission factor data set.

The cooling water use (for all fuels) and the solid waste and water release data for coal were assigned a data quality rating of ‘Unknown’ due to a lack of information on the original data source.

Table 11. Data Sources and Quality Information for the U.S. Electric Grid Inventories

I/O Type [a]	Data	Data Source/ Reference	Data Source Comments	Data Quality [b]	Data Quality Explanation
NONFUEL SPECIFIC					
AR	Criteria pollutants	EPA 1998b	Although the EPA uses measured data wherever feasible in calculating the emissions included in this report, much data required estimating to effectively model the national totals for certain pollutant categories.	Average	Although the bulk of the data used in this analysis were measured, some estimates were required to obtain emissions information from particular industries before aggregating to obtain the U.S.-wide totals.
COAL					
PM	Coal	EIA 1998c	Measured; required for regulatory recording purposes.	Excellent	Measurements provide the highest quality data.
AM	Limestone and lime	EIA 1997	The primary data used in calculating the limestone and lime usage were measured, however approximately six sources of information were accessed to obtain the necessary information to derive final factors.	Average	Of the sources referenced for this calculation, three utilized measured data, while the remaining utilized average or poor quality data. Thus, the overall rating is 'Average.'
AM	Cooling water	CEC 1979	Only source located in which cooling water requirements were detailed for the main electricity generation categories.	Unknown	CEC did not list its data sources.
SW & WR	All	ORNL 1994	Original source of data in the ORNL 1994 report was Meridian Corporation 1989, however, could not be located.	Unknown	Original data document could not be found.
AR	All noncriteria pollutants	EPA 1996	AP-42 factors have a self-assigned 'Average' to 'Poor' quality rating.	Poor	Given 'Poor' rating for several reasons, including primarily that 1) overall AP-42 self-assigned ratings are 'Average' and 2) data applies to 1995.
AR	Methane from coal mining	EPA 1998c	Measured; reported for regulatory recording purposes.	Excellent	Measurements provide the highest quality data.
GAS & PETROLEUM					
PM	Gas and petroleum	EIA 1998c	Measured; required for regulatory recording purposes.	Excellent	Measurements provide the highest quality data.
AM	Cooling water	CEC 1979	Only source located in which cooling water requirements were detailed for the main electricity generation categories.	Unknown	CEC did not list its data sources.
AR	All noncriteria pollutants	EPA 1996	AP-42 factors have a self-assigned 'Poor' quality rating for gas and 'Average' to 'Poor' quality rating for petroleum.	Poor	Given 'Poor' rating for several reasons, including primarily that 1) overall AP-42 self-assigned ratings are 'Average' and 2) data applies to 1995.
URANIUM					
PM	Uranium	EIA 1998b	Measured data, yet had to scale using an unproven scaling mechanism.	Average	Measurements provide the highest quality data, yet the scaling mechanism utilized introduces potential error.
AM	Cooling water	CEC 1979	Only source located in which cooling water requirements were detailed for the main electricity generation categories.	Unknown	CEC did not list its data sources.
SW	Spent fuel	EIA 1996	Estimates the quantity of spent fuel that will be generated in the US in 1997, using measured historical records and knowledge of what facilities will be changing operating patterns in future years (from 1996 perspective).	Excellent	Although not directly measured, use of recently measured data along with in-depth knowledge of future industry changes to project value earns an 'Excellent' rating.
SW	LLRW	Loiselle 1998	Estimated by an industry expert.	Average	Lack of any measured data gives way to an 'Average' rating.
RR	Airborne radionuclides	ORNL 1995	Averaged measured data from nuclear generation facilities.	Excellent	Measurements provide the highest quality data.
RR	Waterborne radionuclides	ORNL 1995	Averaged measured data from nuclear generation facilities.	Excellent	Measurements provide the highest quality data.

[a] Input/Output (I/O) types: PM = primary material, AM = ancillary material, SW = solid waste, AR = airborne release, WR = water release, RR = radioactive release.

[b] The data quality ratings given were assigned to one of the following four data quality categories: Excellent, Average, Poor and Unknown.

5.3 Gas & Petroleum

Each of these data sets utilize the EIA's *Electric Power Annual* for the primary fuel consumption estimates and AP-42 data for the air emissions. The EIA data were given 'Excellent' data quality marks as these data are reported as direct measurements and applicable to 1997. The air emissions were given a quality rating of 'Poor' for the same two reasons the coal inventory data AP-42 estimates were given that rating.

5.4 Uranium

For the nuclear-related inputs and outputs, the largest category of input or output type information was radionuclide emissions. The radionuclide emission information contained in the report was obtained by averaging radionuclide emissions data from 36 different pressurized water reactors (PWRs) across the U.S. (out of just over 110 nuclear reactors total in the U.S.). As discussed previously, the emissions were not found to directly correlate to electricity generation (kWh) or generating capacity (kW), but "were more likely affected by random events within the reactor, such as fuel pin cladding failures, leaks in the primary coolant loop and steam-generator tube leaks" (ORNL 1995). Thus, all factors considered, the overall data quality rating for these emissions was deemed 'Average.' The mass of uranium consumed annually was given the 'Excellent' rating as this information is measured through reporting supplied to the EIA and applicable to 1997.

Of the remaining inputs and outputs, most received higher quality ratings except for the cooling water values which received the 'Unknown' rating due to a lack of information on the original data source.

6. DATA LIMITATIONS

Several limitations of the U.S. electrical energy grid inventory data relate to the exclusion of either entire generation categories (e.g., hydro) or life-cycle substages (see Table 2). For example, no data are readily available for the life-cycle substages of ore and fuel transportation and preliminary ore or fuel processing. Examples of ore and fuel transportation and processing burdens for which insufficient data are available include the emissions generated during the processing of crude oil to produce fuel oils Nos. 6 and 2, and the energy use and wastes generated during the processing of uranium ore into fuel pellets.

With regard to the exclusion of entire generation categories, the renewable and hydroelectric generating categories have not been included in this U.S.-wide inventory. Renewables accounted for only about 0.24% of the total electricity generated in the U.S. in 1997, and are expected to have greatly reduced impacts when compared to the other fuel types. Hydropower was omitted, as stated previously, due to the scarcity of data on hydroelectric inputs and outputs, and also that the CDP LCIA methodology does not account directly for the effects of habitat destruction (expected to be one of the largest impacts from hydroelectric generation once quantified).

Other limitations of the data are related to the use of AP-42 emissions factors, primarily due to the fact that EPA's own ratings of their factors are, at best, 'Average' (see discussion in Section 5.2). Other data limitations include the small number of sources from which much of the data have been obtained. Not necessarily as much a limitation of the data as a limitation in the sources of the data, this is still an area for quality improvement. Also, as noted previously, nonutility electricity generation in the U.S. is excluded from this inventory, and accounts for about 11% of the total electricity generated annually.

There are some implications that can be derived from the limitations mentioned here on the U.S.-wide electric grid inventory data. These implications include the following:

- Since there are currently no other sources of detailed air emission information like AP-42, there is no way of knowing just how accurate their estimates are (possibly predicting a bias in one direction or the other). It appears that the reason that the EPA's quality ratings of their AP-42 data tend toward 'Average' is that in quite a few cases, emissions test were run on only a small number of boilers. Without a larger body of data on which to base the emission factors, it is not known how the use of these factors biases the results.
- The exclusion of the inputs and outputs from materials extraction, the initial and secondary materials processing stages, and the associated transportation for several fuel types (see Table 2) will underestimate the total inventory from electricity generation. Especially when considering the massive amount of processing that is required to develop the uranium fuel pellets that are used in nuclear generation, this may be the largest influence of all the biases for this inventory. (It should also be noted that these processing steps for developing uranium pellets are extremely energy intensive, thus decreasing the efficiency of not only the nuclear electricity generation process, but also the whole grid's overall efficiency as well.)
- The exclusion of the hydropower and renewable generation types should have little effect on the U.S.-wide electric grid inventory data because the renewables are a minimal percentage of the total generation, and hydropower involves no combustion and thus would have minimal impacts.
- The exclusion of the nonutility-type generation brings two major issues forward. First, nonutilities use cogeneration the majority of the time to produce electricity (EIA 1997). Cogeneration utilizes two cycles to produce electrical energy and another form of usable energy (typically steam) thereby increasing the overall efficiency of the energy conversion process. Second, renewables (including hydropower) and gas make up 76% of the energy generation type for nonutilities, two of the lesser polluting types of electricity generation. These two factors should combine to, for the average kWh, decrease not only the quantity of raw materials needed as inputs but also the amount of air emissions generated as outputs for the inventory.

Finally, the Japanese inventory is limited by having been derived from the U.S. fuel-specific inventories and may not accurately represent electricity production operations in Japan.

Overall, with some implications inferring an underestimate in the inventory and some inferring an overestimate, it is uncertain which way the inventory may be biased. To a certain extent, the lessened impacts from the exclusion of nonutility electricity production data seem to offset the exclusion of the processing and transportation life-cycles substages data. However, the exclusion of this relevant data hampers the effort to build a completely accurate and representative electric grid inventory.

7. CONCLUSIONS

The U.S. electric grid inventory data presented in this TM will be used to determine the environmental burdens that result from energy consumption in the U.S. using the CDP LCIA methodology. To summarize the work done in this analysis and its use within the CDP, the following is presented:

- The fuel-specific inventories for each of the four primary generation categories used in the average electric grid were compiled from a variety of sources, and then the fuel-specific inventories were combined using a generation-based weighted average to develop the U.S.-wide and Japanese electrical energy grid inventories of material inputs and pollutant outputs in units of grams of input or output per kWh consumed (except for radioactive materials which were placed in units of Becquerels/kWh).
- The U.S.-wide electrical energy grid inventory data are used in the CDP to calculate material inputs and pollutant outputs from electricity consumed during some manufacturing, use, and final disposal of computer displays.
- The Japanese electrical energy grid inventory data are used in the CDP to calculate material inputs and pollutant outputs from electricity consumed during the manufacturing of monitors in Asia.
- The electrical energy grid data are not used for upstream life-cycle stages (i.e., extraction of materials, materials processing) as these are being obtained from secondary sources which already have included the inputs and outputs from energy consumption.

Once the data have been gathered for all of the CDP processes of interest and the inputs and outputs for each of these processes have been analyzed from a life-cycle perspective, the results will help identify how important the impacts of energy consumption are throughout a monitor's life-cycle.

ACRONYMS/ABBREVIATIONS

CCPCT	Center for Clean Products and Clean Technologies
CEC	California Energy Commission
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FGD	Flue Gas Desulfurization
GWh	Gigawatthour
HCl	Hydrogen chloride
HF	Hydrogen fluoride
kWh	kilowatthour
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LLRW	Low-level radioactive waste
MW	Megawatt
Mwh	Megawatthour
N_2O	Nitrous oxide
NO_X	Oxides of nitrogen
ORNL	Oak Ridge National Laboratory
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PM-10	Particulate matter 10 microns or less in diameter
PWR	Pressurized Water Reactor
SO_2	Sulfur dioxide
TNMOC	Total nonmethane organic carbon
TOC	Total organic carbon
TRI	Toxic Release Inventory
U_3O_8	Uranium oxide
UT	University of Tennessee

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ATTACHMENT A. COAL INFORMATION WORKSPACE

Table A1. Mining Related Outputs - Methane Air Emissions

Pollutant	Quantity [a]	Units	Converted Quantity [b]	Units
Outputs				
Methane	169,906	million ft 3/yr	1.52E+05	million ft 3/yr

[a] Value pertains to methane emissions related to all coal mined nation-wide in U.S. (EPA 1998a).
[b] This value represents methane emissions from coal mined exclusively for electricity generation. It is calculated based on the knowledge that 89.6% of the coal mined in the U.S. in 1997 was for electricity generation, thus the toal methane emissions are multiplied by 89.6% to obtain the emissions from electricity generation alone. (EIA web page: http://www.eia.doe.gov/cneaf/coal/cia/summary/cia_sum.html, 1997).

Table A2. Generation Related Inputs and Outputs - Excluding Air Emissions

Material/Pollutant	Quantity	Units	Converted Quantity	Units
Inputs				
Ancillary Materials				
Water [a]	0.49	gallons/kWh	---	---
Limestone [b]	12,091,817	tons/yr	---	---
Lime [b]	5,310,548	tons/yr	---	---
Outputs				
SOLID WASTES [c]				
Dust/sludge	55.143	tons/GWh	1.10E+02	lbs/MWh
Coal waste	142.857	tons/GWh	2.86E+02	lbs/MWh
Fly/bottom ash	35.714	tons/GWh	7.14E+01	lbs/MWh
WASTEWATER EMISSIONS [c]				
Dissolver	0.278	tons/GWh	5.56E-01	lbs/MWh
Suspended solids	0.005	tons/GWh	1.00E-02	lbs/MWh
Sulfate	0.192	tons/GWh	3.84E-01	lbs/MWh

[a] CEC (1979).
[b] Primary data used to calculate these values from EIA (1997); however, data were modified to derive nationwide average.
[c] ORNL (1994).

Table A3. Generation Related Outputs - Air Emissions [a]

Pollutant	Quantity (lbs/ton of coal)	EPA's Factor Raging [b]
Outputs		
Miscellaneous Compounds [c]		
Methane	0.04	B
Nitrous oxide	0.03	B
Hydrogen chloride	1.2	B
Hydrogen fluoride	0.15	B
Total organic compounds	0.3	E
Total nonmethane organic compounds	0.06	B
Speciated Organic Compounds [d], [e]		
Acetaldehyde	5.70E-04	C
Acetophenone	1.50E-05	D
Acrolein	2.90E-04	D
Benzene	1.30E-03	A
Benzyl chloride	7.00E-04	D
Bis(2-ethyhexyl)pththalate (DEHP)	7.30E-05	D
Bromoform	3.90E-05	E
Carbon disulfide	1.30E-04	D
2-Chloroacetophenone	7.00E-06	E
Chlorobenzene	2.20E-05	D
Chloroform	5.90E-05	E
Cumene	5.30E-06	E
Cyanide	2.50E-03	D
2,4-Dinitrotoluene	2.80E-07	D
Dimethyl sulfate	4.80E-05	E
Ethyl benzene	9.40E-05	D
Ethyl chloride	4.20E-05	D
Ethylene dichloride	4.00E-05	E
Ethylene dibromide	1.20E-06	E
Formaldehyde	2.40E-04	A
Hexane	6.70E-05	D
Isophorone	5.80E-04	D
Methyl bromide	1.60E-04	D
Methyl chloride	5.30E-04	D
Methyl ethyl ketone	3.90E-04	D
Methyl hydrazine	1.70E-04	E
Methyl methacrylate	2.00E-05	E
Methyl tert butyl ether	3.50E-05	E
Methylene chloride	2.90E-04	D

Table A3. Generation Related Outputs - Air Emissions [a]

Pollutant	Quantity (lbs/ton of coal)	EPA's Factor Raging [b]
Phenol	1.60E-05	D
Propionaldehyde	3.80E-04	D
Tetrachloroethylene	4.30E-05	D
Toluene	2.40E-04	A
1,1,1-Trichloroethane	2.00E-05	E
Styrene	2.50E-05	D
Xylenes	3.70E-05	C
Vinyl acetate	7.60E-06	E
Trace Metals [d], [e]		
Antimony	1.80E-05	A
Arsenic	4.10E-04	A
Beryllium	2.10E-05	A
Cadmium	5.10E-05	A
Chromium	2.60E-04	A
Chromium (VI)	7.90E-05	D
Cobalt	1.00E-04	A
Magnesium	1.10E-02	A
Manganese	4.90E-04	A
Mercury	8.30E-05	A
Nickel	2.80E-04	A
Selenium	1.30E-03	A
Polycyclic Aromatic Hydrocarbons [d], [e]		
Biphenyl	1.70E-06	D
Acenaphthene	5.10E-07	B
Acenaphthylene	2.50E-07	B
Anthracene	2.10E-07	B
Benmzo(a)anthracne	8.00E-08	B
Benzo(a)pyrene	3.80E-08	D
Benzo(b,j,k)fluoranthene	1.10E-07	D
Benzo(g,h,i)perylene	2.70E-08	D
Chrysene	1.00E-07	C
Fluoranthene	7.10E-07	B
Fluorene	9.10E-07	B
Indeno(1,2,3-cd)pyrene	6.10E-08	C
Naphthalene	1.30E-05	C
Phenanthrene	2.70E-06	B
Pyrene	3.30E-07	B
5-Methyl chrysens	2.20E-08	D
Dioxins & Furans [d], [f]		

Table A3. Generation Related Outputs - Air Emissions [a]

Pollutant	Quantity (lbs/ton of coal)	EPA's Factor Raging [b]
2,3,7,8-TCDD	1.43E-11	E
Total TCDD	9.28E-11	D
Total PeCDD	4.47E-11	D
Total HxCDD	2.87E-11	D
Total HpCDD	8.34E-11	D
Total OCDD	4.16E-10	D
Total PCDDd	6.66E-10	D
2,3,7,8-TCDF	5.10E-11	D
Total TCDF	4.04E-10	D
Total PeCDF	3.53E-10	D
Total HxCDF	1.92E-10	D
Total HpCDF	7.68E-11	D
Total OCDF	6.63E-11	D
Total PCDFd	1.09E-09	D
TOTAL PCDD/PCDF	1.76E-09	D

[a] All the air emissions presented here are from EPA's AP-42 factors (EPA 1996).
[b] "EPA's AP-42 emissions factor rating is an overall assessment of how good a factor is, based on both the quality of the test(s) or information that is the source of the factor and on how well the factor represents the emission source." (EPA 1996) EPA's factor ratings are as follows:
A = Excellent; B = Above Average; C = Average; D = Below Average; and E = Poor.
[c] Due to a lack of data on firing configurations for all U.S. boilers, the pulverized coal (PC), dry, wall-fired boiler firing configuration (the most common configuration in the U.S.) was chosen as the representative configuration. Additionally, the factors for methane, nitrous oxide,, total organic compounds and total nonmethane organic compounds are for uncontrolled emissions, while the values for hydrogen chloride and hydrogen fluoride are for controlled and uncontrolled emissions (measurements were taken from different facilities were some had control equipment and others did not).
[d] These are all controlled factors.
[e] Apply to bituminous, subbituminous and ignite coal types. Even though these factors apply only to these three coal types, the emission factors are applied to all coal types. This was done for two reasons: 1) because no factors were given for the remaining coal types; and 2) those remaining coal types do generate some of these emissions, and it would have been erroneous to consider then 'pollutant-free."
[f] Apply to bituminous and subbituminous coal types. Even though these factors apply only to these two coal types, the emission factors are applied to all coal types. This was done for two reasons: 1) because no factors were given for the remaining coal types; and 2) those remaining coal types do generate some of these emissions, and it would have been erroneous to consider them 'pollutant-free.'

ATTACHMENT B. GAS INFORMATION WORKSPACE

Table B1. Generation Related Inputs

Material	Quantity	Units
Inputs		
Ancillary Materials		
Water [a]	0.25	gallons/kWh

[a] CEC (1979). The value listed under 'Combined Cycle' in the reference was used for gas-fired generation since the majority of combined cycle units's top cycle is fired by gas.

Table B2. Generation Related Outputs

Pollutant	Quantity (lbs/million ft3 of gas)	EPA's factor rating [b]
Outputs		
AIR EMISSIONS [a]		
Miscellaneous Compounds [c]		
Nitrous oxide	2.2	C
Total organic compounds	1.7	C
Speciated Organic Compounds [d]		
Fluoranthene	3.10E-06	E
Formaldehyde	1.55E-01	C
2-Methylnaphthalene	9.02E-06	E
Naphthalene	2.40E-04	E
Phenanthrene	1.00E-05	E
Pyrene	5.10E-06	E
Toluene	2.20E-03	E
Trace Metals [e]		
Arsenic	2.30E-04	E
Barium	2.40E-03	E
Chromium	1.10E-03	E
Cobalt	1.20E-04	E
Copper	2.51E-04	E
Manganese	3.81E-04	E
Molybdenum	5.81E-04	E
Nickel	3.61E-03	E
Vanadium	3.21E-03	E

[a] All outputs for gas-fired generation are air emissions and are from the EPA's AP-42 emission factors (EPA 1996).
[b] "EPA's AP-42 emissions factor rating is an overall assessment of how good a factor is, based on both the quality of the test(s) or information that is the source of the factor and how well the factor represents the emission source (EPA 1996). EPA's factor ratings are as follows: A = Excellent; B = Above Average; C = Average; D = Below Average; and E = Poor.
[c] Factors are for uncontrolled combustion.
[d] Each of the seven factors provided are for controlled and uncontrolled combustion.
[e] Factors are for controlled combustion.

ATTACHMENT C. PETROLEUM INFORMATION WORKSPACE

Table C1. Generation Related Inputs

Material	Quantity	Units
Inputs		
ANCILLARY MATERIALS		
Water [a]	0.43	gallons/kWh

[a] CEC (1979).

Table C2. Generation Related Outputs

Pollutant	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]
	Fuel Oil #6		**Fuel Oil #2**		**Average Factors**	
Outputs						
AIR EMISSIONS [a]						
Miscellaneous Compounds [c]						
Methane	0.28	A	0.052	A	2.66E-01	A
Nitrous oxide	0.11	B	0.11	B	1.10E-01	B
Total organic compounds	1.04	A	0.252	A	9.93E-01	A
Total nonmethane organic compounds	0.76	A	0.2	A	7.26E-01	A
Speciated Organic Compounds [d]						
Acenaphthene	2.11E-05	C			2.11E-05	C
Acenaphthylene	2.53E-07	D			2.53E-07	D
Anthracene	1.22E-06	C			1.22E-06	C
Benzene	2.14E-04	C			2.14E-04	C
Benz(a)anthracene	4.01E-06	C			4.01E-06	C
Benzo(b,k)fluoranthene	1.48E-06	C			1.48E-06	C
Benzo(g,h,i)perylene	2.26E-06	C			2.26E-06	C
Chrysene	2.38E-06	C			2.38E-06	C
Dibenzo(a,h)anthracene	1.67E-06	D			1.67E-06	D
Ethylbenzene	6.36E-05	E			6.36E-05	E
Fluoranthene	4.84E-06	C			4.84E-06	C
Fluorene	4.47E-06	C			4.47E-06	C
Formaldehyde	3.30E-02	C			3.30E-02	C
Indo(1,2,3-cd)pyrene	2.14E-06	C			2.14E-06	C
Naphthalene	1.13E-03	C			1.13E-03	C
OCDD	3.10E-09	E			3.10E-09	E
Phenanthrene	1.05E-05	C			1.05E-05	C
Pyrene	4.25E-06	C			4.25E-06	C
Toluene	6.20E-03	D			6.20E-03	D

Table C2. Generation Related Outputs

Pollutant	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]	Quantity (lbs/thousand gallons of oil)	EPA's factor rating [b]
	Fuel Oil #6		Fuel Oil #2		Average Factors	
1,1,1-Trichloroethane	2.36E-04	E			2.36E-04	E
o-xylene	1.09E-04	E			1.09E-04	E
Trace Metals [e]						
Antimony	5.25E-03	E			5.25E-03	E
Arsenic	1.32E-03	C	5.88E-04	E	1.28E-03	C
Barium	2.57E-03	D			2.57E-03	D
Beryllium	2.78E-05	C	3.50E-04	E	4.71E-05	C
Cadmium	3.98E-04	C	1.54E-03	E	4.67E-04	C
Chloride	3.47E-01	D			3.47E-01	D
Chromium	8.45E-04	C	8.05E-03	E	1.28E-03	C
Chromium (VI)	2.48E-04	C			2.48E-04	C
Cobalt	6.02E-03	D			6.02E-03	D
Copper	1.76E-03	C			1.76E-03	C
Fluoride	3.73E-02	D			3.73E-02	D
Manganese	3.00E-03	C	1.96E-03	E	2.94E-03	C
Mercury	1.13E-04	C	4.20E-04	E	1.31E-04	C
Molybdenum	7.87E-04	D			7.87E-04	D
Nickel	8.45E-02	C	2.38E-02	E	8.09E-02	C
Phosphorous	9.46E-03	D			9.46E-03	D
Selenium	6.83E-04	C			6.83E-04	C
Vanadium	3.18E-02	D			3.18E-02	D
Zinc	2.91E-02	D			2.91E-02	D

[a] All outputs for oil-fired generation are air emissions and are from the EPA's AP-42 emission factors (EPA 1996).
[b] "EPA's AP-42 emissions factor rating is an overall assessment of how good a factor is, based on both the quality of the test(s) or information that is the source of the factor and on how well the factor represents the emission source" (EPA 1996). EPA's factor ratings are as follows: A = Excellent; B = Above Average; C = Average; D = Below Average; and E = Poor.
[c] Factors are for uncontrolled combustion of all pollutants, except for N2O. No information was provided as to the control of N2O emissions.
[d] No information was provided as to the control of these pollutants. No emission factors were presented for fuel oil #2, thus, the factors for #6 were considered the same for #2. Even though one could assume that fuel oil #2 should have smaller quantities of pollutants to contribute per equivalent volume than fuel oil #6 (due to #6 being a residual oil and # 2 being a distillate), some of the results from the trace metals table contradict that assumption, thus substantiating this action.
[e] No information was provided as to the control of these pollutants. Where no fuel oil #2 emission factor was given, the factor for fuel oil #6 was used for both fuel oils. Even though one could assume that fuel oil #2 should have smaller quantities of pollutants to contribute per equivalent volume than fuel oil #6, some of the results from this table (where factors were reported for both fuel oils) contradict that assumption, thus substantiating this action.

Table C3. Miscellaneous Calculation Information

	Quantity	Unit	Quantity	Unit
	Fuel Oil #6		Fuel Oil #2	
Type of petroleum used at utilities [a]	94	%	6	%
AP-42 heat values for fuel oils [f]	152,000	btu/gal	140,000	but/gal

[a] Source: EIA's "Cost & Quality of Fuels for Electric Utility Plants 1997."
[b] EPA (1996).

ATTACHMENT D. NUCLEAR INFORMATION WORKSPACE

Table D1. Generation Related Inputs and Outputs - Excluding Radionuclide Emissions

Material/Pollutant	Quantity	Units	Converted Quantity	Units
Inputs				
PRIMARY MATERIALS				
Uranium oxide [a]	48,700,000	lbs/yr	---	---
ANCILLARY MATERIALS				
Water [b]	0.62	gallons/kWh	---	---
Outputs				
SOLID/HAZARDOUS WASTES				
Uranium (spent fuel generated) [c]	2,400	metric tons/yr	5.29E+06	lbs/yr
Low-level radioactive waste [d]	220,500	cubic feet/yr	---	---

[a] Known as 'yellowcake,' this post-milling uranium product is sent to conversion facilities (EIA 1998b).
[b] CEC (1979).
[c] EIA (1996); Table 18.
[d] Loisell (1998).

Table D2. Generation Related Outputs - Radionuclide Emissions

Isotope	Quantity	Units	Converted Quantity	Units [d]
Outputs [a], [b], [c]				
AIRBORNE RADIONUCLIDE EMISSIONS				
T-3	5.98E+01	Curies/yr	7.33E-06	Curies/MWh
Ar-41	2.55E+01	Curies/yr	3.13E-06	Curies/MWh
Cr-51	1.60E-03	Curies/yr	1.96E-10	Curies/MWh
Mn-54	2.27E-05	Curies/yr	2.78E-12	Curies/MWh
Co-57	4.30E-06	Curies/yr	5.27E-13	Curies/MWh
Co-58	5.49E-05	Curies/yr	6.73E-12	Curies/MWh
Co-60	4.13E-04	Curies/yr	5.06E-11	Curies/MWh
Kr-85	4.23E+01	Curies/yr	5.18E-06	Curies/MWh
Kr-85M	2.05E+00	Curies/yr	2.51E-07	Curies/MWh
Kr-87	7.63E-01	Curies/yr	9.35E-08	Curies/MWh
Rb-88	8.38E-03	Curies/yr	1.03E-09	Curies/MWh
Kr-88	3.58E+00	Curies/yr	4.39E-07	Curies/MWh
Br-89	2.95E-06	Curies/yr	3.62E-13	Curies/MWh
Br-90	1.20E-06	Curies/yr	1.47E-13	Curies/MWh
Nb-95	9.02E-07	Curies/yr	1.11E-13	Curies/MWh
Zr-95	2.33E-06	Curies/yr	2.86E-13	Curies/MWh
Tc-99M	1.21E-07	Curies/yr	1.48E-14	Curies/MWh
Ag-110M	2.69E-08	Curies/yr	3.30E-15	Curies/MWh
I-131	1.93E-03	Curies/yr	2.37E-10	Curies/MWh

Table D2. Generation Related Outputs - Radionuclide Emissions

Isotope	Quantity	Units	Converted Quantity	Units [d]
Xe-131M	3.45E+00	Curies/yr	4.23E-07	Curies/MWh
I-132	3.92E-04	Curies/yr	4.80E-11	Curies/MWh
Xe-133	4.98E+02	Curies/yr	6.10E-05	Curies/MWh
I-133	1.79E+00	Curies/yr	2.19E-07	Curies/MWh
Xe-133M	3.31E+01	Curies/yr	4.06E-06	Curies/MWh
Cs-134	8.10E-05	Curies/yr	9.93E-12	Curies/MWh
I-134	2.03E-03	Curies/yr	2.49E-10	Curies/MWh
Xe-135	1.88E+01	Curies/yr	2.30E-06	Curies/MWh
I-135	1.02E-04	Curies/yr	1.25E-11	Curies/MWh
Xe-135M	3.59E-01	Curies/yr	4.40E-08	Curies/MWh
Cs-137	6.11E-04	Curies/yr	7.49E-11	Curies/MWh
Xe-138	1.19E+00	Curies/yr	1.46E-07	Curies/MWh
T-3	4.47E+02	Curies/yr	5.48E-05	Curies/MWh
Na-24	2.24E-03	Curies/yr	2.75E-10	Curies/MWh
Cr-51	6.07E-02	Curies/yr	7.44E-09	Curies/MWh
Mn-54	4.00E-02	Curies/yr	4.90E-09	Curies/MWh
Fe-55	1.43E-01	Curies/yr	1.75E-08	Curies/MWh
Co-57	1.47E-03	Curies/yr	1.80E-10	Curies/MWh
Co-58	5.98E-01	Curies/yr	7.33E-08	Curies/MWh
Fe-59	7.34E-03	Curies/yr	9.00E-10	Curies/MWh
Co-80	1.57E-01	Curies/yr	1.92E-08	Curies/MWh
Zn-85	6.75E-04	Curies/yr	8.27E-11	Curies/MWh
Kr-85M	3.78E-02	Curies/yr	4.63E-09	Curies/MWh
Sr-89	2.42E-03	Curies/yr	2.97E-10	Curies/MWh
Sr-90	5.69E-04	Curies/yr	6.97E-11	Curies/MWh
Nb-95	1.03E-02	Curies/yr	1.26E-09	Curies/MWh
Sr-95	6.27E-03	Curies/yr	7.68E-10	Curies/MWh
Mo-99	7.55E+04	Curies/yr	9.25E-03	Curies/MWh
Tc-99M	8.78E-04	Curies/yr	1.08E-10	Curies/MWh
Ru-103	1.26E-03	Curies/yr	1.54E-10	Curies/MWh
Ag-110M	1.47E-02	Curies/yr	1.80E-09	Curies/MWh
Sn-113	1.39E-03	Curies/yr	1.70E-10	Curies/MWh
Sb-124	1.26E-02	Curies/yr	1.54E-09	Curies/MWh
Sb-125	5.02E-02	Curies/yr	6.15E-09	Curies/MWh
I-131	2.80E-02	Curies/yr	3.43E-09	Curies/MWh
Xe-131M	4.60E-01	Curies/yr	5.64E-08	Curies/MWh
I-132	1.06E-02	Curies/yr	1.30E-09	Curies/MWh
Xe-133	7.07E+01	Curies/yr	8.66E-06	Curies/MWh
I-133	1.20E-02	Curies/yr	1.47E-09	Curies/MWh

Table D2. Generation Related Outputs - Radionuclide Emissions

Isotope	Quantity	Units	Converted Quantity	Units [d]
Xe-133M	5.79E-01	Curies/yr	7.10E-08	Curies/MWh
Cs-134	3.37E-02	Curies/yr	4.13E-09	Curies/MWh
I-135	8.61E-03	Curies/yr	1.06E-09	Curies/MWh
Xe-135	5.27E-01	Curies/yr	6.46E-08	Curies/MWh
s-136	1.35E-03	Curies/yr	1.65E-10	Curies/MWh
Cs-137	5.06E-02	Curies/yr	6.20E-09	Curies/MWh
Ba-140	9.34E-04	Curies/yr	1.14E-10	Curies/MWh
La-140	1.00E-03	Curies/yr	1.23E-10	Curies/MWh

[a] ORNL (1995).
[b] There were 111 operating commercial nuclear power stations in the U.S. in 1995, of which 75 were PWRs (presssurized-water reactors) and 36 were BWRs (boiling-water reactors). Of the PWRs, 52 were designed by Westinghouse; the remaining 23 were designed by either ABB or Babcock & Wilcox. From the available data, the authors chose to use data from all Westinghouse PWRs with greater than 800 MWS capacity (36 facilities) in attempts to gather consistent data for
their calculations on transport and dose-effects for their reference PWR.
[c] "These emissions are characterisitc of normal (nonaccident) emissions, and did not appear to readily correlate to MWhs produced or reactor capacity. Amounts produced are more likely affected by random events within reactor, such as fuel pin cladding failures, leaks in the primary coolant loop, steam-generator tube leaks, etc." (ORNL 1995, pp. 6-35 & 6-36).
[d] The units of Curies/MWh were derived by dividing the Curies/yr values by the number of MWhs produced annually in the virtual facility discussed in the source for this information (8,160,000 MWh/yr).

ATTACHMENT E. SUMMARY INFORMATION WORKSPACE

Notes:
• In the tables in this Appendix, "US kWh" is utilized to identify values that are representative of an average U.S. kWh in 1997.
• Unless stated otherwise, the sources for the data presented here are detailed in Attachments A through D.

Table E1. Generation Related Inputs and Outputs - Excluding Air Emissions

Material/Pollutant	Quantity	Units	Converted Quantity	Units
Inputs				
PRIMARY MATERIALS				
Coal	900,361,000	tons/yr	2.83E+02	grams/US kWh
Gas	2,968,453,000,000	ft3/yr	2.20E+01	grams/US kWh
Petroleum	5,256,132,000	agal/yr	5.99E+00	grams/US kWh
Uranium (yellow cake)	48,700,000	lbs/yr	7.64E-03	grams/US kWh
ANCILLARY MATERIALS				
Limestone	12,091,817	tons/yr	3.79E+00	grams/US kWh
Lime	5,310,548	tons/yr	1.67E+00	grams/US kWh
Water	11,426,836,328,400	lbs/yr	1.79E+03	grams/US kWh
Outputs				
SOLID WASTES				
Dust/sludge	197,169,972,516	lbs/yr	3.09E+01	grams/US kWh
Coal waste	510,801,203,484	lbs/yr	8.01E+01	grams/US kWh
Fly/bottom ash	127,699,406,968	lbs/yr	2.00E+01	grams/US kWh
Uranium (spent fuel generated)	1.83E-06	lbs/kWh	8.30E-04	grams/US kWh
LLRW	6.10E-06	lbs/kWh	2.77E-03	grams/US kWh
WATER RELEASES				
Dissolver	994,020,136	lbs/yr	1.56E-01	grams/US kWh
Suspended solids	17,878,060	lbs/yr	2.80E-03	grams/US kWh
Sulfate	686,517,504	lbs/yr	1.08E-01	grams/US kWh

Table E2. Generation Related Outputs - Air Emissions

Pollutant	Quantity	Units	Converted Quantity	Units
Outputs				
Criteria Pollutants [a]				
Carbon dioxide	2,231,433,058	tons/yr	6.48E+02	grams/US kWh
Nitrogen oxides	6,178,000	tons/yr	1.79E+00	grams/US kWh
Sulfur dioxide	13,082,000	tons/yr	3.80E+00	grams/US kWh
Carbon monoxide	406,000	tons/yr	1.18E-01	grams/US kWh
Lead	64	tons/yr	1.86E-05	grams/US kWh
Particulate matter (10 microns or less)	290,000	tons/yr	8.43E-02	grams/US kWh
Uncategorized Pollutants				
Methane (includes coal mining releases)	6,473,160,931	lbs/yr	1.02E+00	grams/US kWh
Nitrous oxide	34,119,601	lbs/yr	5.35E-03	grams/US kWh
Hydrogen chloride	1,080,433,200	lbs/yr	1.70E-01	grams/US kWh
Hydrogen fluoride	135,054,150	lbs/yr	2.12E-02	grams/US kWh
Total organic compounds	280,372,537	lbs/yr	4.40E-02	grams/US kWh
Total nonmethane organic compounds	57,839,714	lbs/yr	9.07E-03	grams/US kWh
Speciated Organic Compounds				
Acetaldehyde	513,206	lbs/yr	8.05E-05	grams/US kWh
Acetophenone	13,505	lbs/yr	2.12E-06	grams/US kWh
Acrolein	261,105	lbs/yr	4.10E-05	grams/US kWh
Benzene	1,171,594	lbs/yr	1.84E-04	grams/US kWh
Benzo(b,k)fluoranthene	8	lbs/yr	1.22E-09	grams/US kWh
Benzyl chloride	630,253	lbs/yr	9.89E-05	grams/US kWh
Bis(2-ethylhexyl)phthalate (DEHP)	65,726	lbs/yr	1.03E-05	grams/US kWh
Bromoform	35114.079	lbs/yr	5.51E-06	grams/US kWh
2-Chloroacetophenone	6302.527	lbs/yr	9.89E-07	grams/US kWh
Carbon disulfide	117046.93	lbs/yr	1.84E-05	grams/US kWh
Chlorobenzene	19807.942	lbs/yr	3.11E-06	grams/US kWh
Chloroform	53121.299	lbs/yr	8.33E-06	grams/US kWh
Cumene	4771.9133	lbs/yr	7.49E-07	grams/US kWh
Cyanide	2250902.5	lbs/yr	3.53E-04	grams/US kWh
2,4-Dinitrotoluene	252.10108	lbs/yr	3.96E-08	grams/US kWh
Dibenzo(a,h)anthracene	8.77774044	lbs/yr	1.38E-09	grams/US kWh
Dimethyl sulfate	43217.328	lbs/yr	6.78E-06	grams/US kWh
Ethyl benzene	84968.224	lbs/yr	1.33E-05	grams/US kWh
Ethyl chloride	37815.162	lbs/yr	5.93E-06	grams/US kWh
Ethylene dichloride	36014.44	lbs/yr	5.65E-06	grams/US kWh
Ethylene dibromide	1080.4332	lbs/yr	1.70E-07	grams/US kWh

Table E2. Generation Related Outputs - Air Emissions

Pollutant	Quantity	Units	Converted Quantity	Units
Formaldehyde	849649.211	lbs/yr	1.33E-04	grams/US kWh
Hexane	60324.187	lbs/yr	9.46E-06	grams/US kWh
Indo(1,2,3-cd)pyrene	11.24812248	lbs/yr	1.76E-09	grams/US kWh
Isophorone	522209.38	lbs/yr	8.19E-05	grams/US kWh
2-Methylnaphthalene	26.77544606	lbs/yr	4.20E-09	grams/US kWh
Methyl bromide	144057.76	lbs/yr	2.26E-05	grams/US kWh
Methyl chloride	477191.33	lbs/yr	7.49E-05	grams/US kWh
Methyl ethyl ketone	351140.79	lbs/yr	5.51E-05	grams/US kWh
Methyl hydrazine	153061.37	lbs/yr	2.40E-05	grams/US kWh
Methyl methacrylate	18007.22	lbs/yr	2.83E-06	grams/US kWh
Methyl tert butyl ether	31512.635	lbs/yr	4.94E-06	grams/US kWh
Methylene chloride	261104.69	lbs/yr	4.10E-05	grams/US kWh
OCDD	0.016294009	lbs/yr	2.56E-12	grams/US kWh
Phenol	14405.776	lbs/yr	2.26E-06	grams/US kWh
Propionaldehyde	342137.18	lbs/yr	5.37E-05	grams/US kWh
Tetrachloroethylene	38715.523	lbs/yr	6.07E-06	grams/US kWh
Toluene	255205.255	lbs/yr	4.00E-05	grams/US kWh
1,1,1-Trichloroethane	19247.66715	lbs/yr	3.02E-06	grams/US kWh
Styrene	22509.025	lbs/yr	3.53E-06	grams/US kWh
Xylenes	33313.357	lbs/yr	5.23E-06	grams/US kWh
o-xylene	572.918388	lbs/yr	8.99E-08	grams/US kWh
Vinyl acetate	6842.7436	lbs/yr	1.07E-06	grams/US kWh
Trace Metals				
Antimony	43,801	lbs/yr	6.87E-06	grams/US kWh
Arsenic	376,538	lbs/yr	5.91E-05	grams/US kWh
Barium	20,633	lbs/yr	3.24E-06	grams/US kWh
Beryllium	19,155	lbs/yr	3.01E-06	grams/US kWh
Cadmium	48,371	lbs/yr	7.59E-06	grams/US kWh
Chloride	1,823,878	lbs/yr	2.86E-04	grams/US kWh
Chromium	244,073	lbs/yr	3.83E-05	grams/US kWh
Chromium (VI)	72,432	lbs/yr	1.14E-05	grams/US kWh
Cobalt	122,034	lbs/yr	1.91E-05	grams/US kWh
Copper	9,996	lbs/yr	1.57E-06	grams/US kWh
Fluoride	196,054	lbs/yr	3.08E-05	grams/US kWh
Magnesium	9,903,971	lbs/yr	1.55E-03	grams/US kWh
Manganese	457,748	lbs/yr	7.18E-05	grams/US kWh
Mercury	75,421	lbs/yr	1.18E-05	grams/US kWh
Molybdenum	5,861	lbs/yr	9.20E-07	grams/US kWh
Nickel	687,818	lbs/yr	1.08E-04	grams/US kWh
Phosphorous	49,723	lbs/yr	7.80E-06	grams/US kWh

Table E2. Generation Related Outputs - Air Emissions

Pollutant	Quantity	Units	Converted Quantity	Units
Selenium	1,174,059	lbs/yr	1.84E-04	grams/US kWh
Vanadium	176,674	lbs/yr	2.77E-05	grams/US kWh
Zinc	152,953	lbs/yr	2.40E-05	grams/US kWh
Polynuclear Aromatic Hydrocarbons (PAHs)				
Biphenyl	1,531	lbs/yr	2.40E-07	grams/US kWh
Acenaphthene	459	lbs/yr	8.94E-08	grams/US kWh
Acenaphthylene	225	lbs/yr	3.55E-08	grams/US kWh
Anthracene	189	lbs/yr	3.07E-08	grams/US kWh
Benzo(a)anthracene	72	lbs/yr	1.46E-08	grams/US kWh
Benzo(a)pyrene	34	lbs/yr	5.37E-09	grams/US kWh
Benzo(b,j,k)fluoranthene	99	lbs/yr	1.55E-08	grams/US kWh
Benzo(g,h,i)perylene	24	lbs/yr	5.68E-09	grams/US kWh
Chrysene	90	lbs/yr	1.61E-08	grams/US kWh
Fluoranthene	639	lbs/yr	1.06E-07	grams/US kWh
Fluorene	819	lbs/yr	1.32E-07	grams/US kWh
Indeno(1,2,3-cd)pyrene	55	lbs/yr	8.62E-09	grams/US kWh
Naphthalene	11,705	lbs/yr	2.88E-06	grams/US kWh
Phenanthrene	2,431	lbs/yr	3.95E-07	grams/US kWh
Pyrene	297	lbs/yr	5.25E-08	grams/US kWh
5-Methyl chrysene	20	lbs/yr	3.11E-09	grams/US kWh
Dioxins & Furans				
2,3,7,8-TCDD	0.012875162	lbs/yr	2.02E-12	grams/US kWh
Total TCDD	0.083553501	lbs/yr	1.31E-11	grams/US kWh
Total PeCDD	0.040246137	lbs/yr	6.31E-12	grams/US kWh
Total HxCDD	0.025840361	lbs/yr	4.05E-12	grams/US kWh
Total HpCDD	0.075090107	lbs/yr	1.18E-11	grams/US kWh
Total OCDD	0.374550176	lbs/yr	6.13E-11	grams/US kWh
Total PCDDd	0.599640426	lbs/yr	9.41E-11	grams/US kWh
2,3,7,8-TCDF	0.045918411	lbs/yr	7.20E-12	grams/US kWh
Total TCDF	0.363745844	lbs/yr	5.71E-11	grams/US kWh
Total PeCDF	0.317827433	lbs/yr	4.99E-11	grams/US kWh
Total HxCDF	0.172869312	lbs/yr	2.71E-11	grams/US kWh
Total HpCDF	0.069147725	lbs/yr	1.08E-11	grams/US kWh
Total OCDF	0.059693934	lbs/yr	9.37E-12	grams/US kWh
Total PCDFd	0.98139349	lbs/yr	1.54E-10	grams/US kWh
TOTAL PCDD/PCDF	1.58463536	lbs/yr	2.49E-10	grams/US kWh

[a] The criteria pollutants were not multiplied by the transmission and distribution factor due to their being reported totals for the electric industry.

Table E3. Generation Related Outputs - Radionuclides

Isotope	Quantity	Units	Converted Quality	Units
Outputs				
Airborne Radionuclides				
T-3	4606.974412	Curies/yr	5.90E+01	Becquerels/US kWh
Ar-41	1964.5125	Curies/yr	2.51E+01	Becquerels/US kWh
Cr-51	0.123263529	Curies/yr	1.58E-03	Becquerels/US kWh
Mn-54	0.001748801	Curies/yr	2.24E-05	Becquerels/US kWh
Co-57	0.000331271	Curies/yr	4.24E-06	Becquerels/US kWh
Co-58	0.00422948	Curies/yr	5.41E-05	Becquerels/US kWh
Co-60	0.031817399	Curies/yr	4.07E-04	Becquerels/US kWh
Kr-85	3258.779559	Curies/yr	4.17E+01	Becquerels/US kWh
Kr-85M	157.9313971	Curies/yr	2.02E+00	Becquerels/US kWh
Kr-87	58.78129559	Curies/yr	7.52E-01	Becquerels/US kWh
Rb-88	0.645592735	Curies/yr	8.26E-03	Becquerels/US kWh
Kr-88	275.8021471	Curies/yr	3.53E+00	Becquerels/US kWh
Br-89	0.000227267	Curies/yr	2.91E-06	Becquerels/US kWh
Br-90	9.24476E-05	Curies/yr	1.18E-06	Becquerels/US kWh
Nb-95	6.94898E-05	Curies/yr	8.89E-07	Becquerels/US kWh
Zr-95	0.000179503	Curies/yr	2.30E-06	Becquerels/US kWh
Tc-99M	9.3218E-06	Curies/yr	1.19E-07	Becquerels/US kWh
Ag-110M	2.07237E-06	Curies/yr	2.65E-08	Becquerels/US kWh
I-131	0.148686632	Curies/yr	1.90E-03	Becquerels/US kWh
Xe-131M	265.7869853	Curies/yr	3.40E+00	Becquerels/US kWh
I-132	0.030199565	Curies/yr	3.86E-04	Becquerels/US kWh
Xe-133	38365.77353	Curies/yr	4.91E+02	Becquerels/US kWh
I-133	137.9010735	Curies/yr	1.76E+00	Becquerels/US kWh
Xe-133M	2550.014265	Curies/yr	3.26E+01	Becquerels/US kWh
Cs-134	0.006240216	Curies/yr	7.99E-05	Becquerels/US kWh
I-134	0.156390603	Curies/yr	2.00E-03	Becquerels/US kWh
Xe-135	1448.346471	Curies/yr	1.85E+01	Becquerels/US kWh
I-135	0.00785805	Curies/yr	1.01E-04	Becquerels/US kWh
Xe-135M	27.65725441	Curies/yr	3.54E-01	Becquerels/US kWh
Cs-137	0.04707126	Curies/yr	6.02E-04	Becquerels/US kWh
Xe-138	91.67725	Curies/yr	1.17E+00	Becquerels/US kWh
Waterborne Radionuclides				
T-3	34436.74853	Curies/yr	4.41E+02	Becquerels/US kWh
Na-24	0.172568941	Curies/yr	2.21E-03	Becquerels/US kWh
Cr-51	4.676310147	Curies/yr	5.98E-02	Becquerels/US kWh
Mn-54	3.081588235	Curies/yr	3.94E-02	Becquerels/US kWh
Fe-55	11.01667794	Curies/yr	1.41E-01	Becquerels/US kWh
Co-57	0.113248368	Curies/yr	1.45E-03	Becquerels/US kWh
Co-58	46.06974412	Curies/yr	5.90E-01	Becquerels/US kWh
Fe-59	0.565471441	Curies/yr	7.24E-03	Becquerels/US kWh

Table E3. Generation Related Outputs - Radionuclides

Isotope	Quantity	Units	Converted Quality	Units
Co-80	12.09523382	Curies/yr	1.55E-01	Becquerels/US kWh
Zn-85	0.052001801	Curies/yr	6.65E-04	Becquerels/US kWh
Kr-85M	2.912100882	Curies/yr	3.73E-02	Becquerels/US kWh
Sr-89	0.186436088	Curies/yr	2.39E-03	Becquerels/US kWh
Sr-90	0.043835593	Curies/yr	5.61E-04	Becquerels/US kWh
Nb-95	0.793508971	Curies/yr	1.02E-02	Becquerels/US kWh
Sr-95	0.483038956	Curies/yr	6.18E-03	Becquerels/US kWh
Mo-99	5816497.794	Curies/yr	7.44E+04	Becquerels/US kWh
Tc-99M	0.067640862	Curies/yr	8.66E-04	Becquerels/US kWh
Ru-103	0.097070029	Curies/yr	1.24E-03	Becquerels/US kWh
Ag-110M	1.132483676	Curies/yr	1.45E-02	Becquerels/US kWh
Sn-113	0.107085191	Curies/yr	1.37E-03	Becquerels/US kWh
Sb-124	0.970700294	Curies/yr	1.24E-02	Becquerels/US kWh
Sb-125	3.867393235	Curies/yr	4.95E-02	Becquerels/US kWh
I-131	2.157111765	Curies/yr	2.76E-02	Becquerels/US kWh
Xe-131M	35.43826471	Curies/yr	4.54E-01	Becquerels/US kWh
I-132	0.816620882	Curies/yr	1.05E-02	Becquerels/US kWh
Xe-133	5446.707206	Curies/yr	6.97E+01	Becquerels/US kWh
I-133	0.924476471	Curies/yr	1.18E-02	Becquerels/US kWh
Xe-133M	44.60598971	Curies/yr	5.71E-01	Becquerels/US kWh
Cs-134	2.596238088	Curies/yr	3.32E-02	Becquerels/US kWh
I-135	0.663311868	Curies/yr	8.49E-03	Becquerels/US kWh
Xe-135	40.599925	Curies/yr	5.20E-01	Becquerels/US kWh
s-136	0.104003603	Curies/yr	1.33E-03	Becquerels/US kWh
Cs-137	3.898209118	Curies/yr	4.99E-02	Becquerels/US kWh
Ba-140	0.071955085	Curies/yr	9.21E-04	Becquerels/US kWh
La-140	0.077039706	Curies/yr	9.86E-04	Becquerels/US kWh

Table E4. Net Generation Information

Generation type [a]	Net Generation	
	(MWh/yr)	%
Coal	1,787,806,000	57.255%
Gas	283,625,000	9.083%
Petroleum	77,753,000	2.490%
Nuclear	628,644,000	20.133%
Hydro [b]	337,233,000	10.800%
Renewables [b]	7,462,000	0.239%
Total	3,122,522,000	100.000%

[a] This breakdown excludes nonutility electricity generation (Non and Independent Power Producers (NPPs or IPPs)), which typically contribute about 11% of the U.S. total (EIA 1999).
[b] Hydro and renewables were excluded from the calculation of inputs and outputs.

Table E5. Conversion Factors

Universal factor	1 pound =	453.59	grams
Water	1 gallon =	8.34	pounds
Coal [a]	1 pound =	10,275	btu
Gas [b]	a cubic foot =	0.0473	pounds
Petroleum	1 gallon =	7.26	pounds
Nuclear	1 Curie =	3.70E+10	Becquerals
Nuclear (LLRW)	1 cubic foot =	80	pounds
Transmission & distribution [c]	1 kWh out requires =	1.08	kWhs in

[a] Source: EIA's "Cost & Quality of Fuels for Electric Utility Plants 1997," Table ES-4.
[b] Calculated by the CCPCT with reference information from "Perry's Chemical Engineer's Handbook, 6th Edition."
[c] Source: EIA's Short-Term Energy Outlook," Table A8.